The Concept of an Innovative Educational Ecosystem of Ukraine in the Context of the Approach "Education 4.0 for Industry 4.0"

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Abstract

The article describes the educational ecosystem as an environment for creating conditions that increase the competitiveness of universities, organizations, territories and regions. The paper notes that society is on the verge of radical changes in the educational paradigm, as a result of which universities play a crucial role in the implementation of innovations and commercialization of scientific and technical developments. The authors substantiate the role of transformation processes in Industry 4.0, which require reform of educational ecosystems in universities. It is shown that the ecosystem approach to education can be more efficient and effective compared to traditional hierarchical models. The components of the innovative educational ecosystem and the mechanisms of interaction of its members are considered. A conceptual model of the digital education ecosystem based on educational- production clusters as a universal cooperation model of complex nonlinear systems is proposed. The authors see the basis of the ecosystem as an innovative platform that allows you to regulate many horizontal communications in the form of research centres, innovation laboratories, startup schools. The implementation of an innovative educational model of the ecosystem is illustrated by examples of innovative ecosystems Sikorsky Challenge and SoftServe Corporate University. The methodological basis of the study is a systems approach, competence approach, and theory of innovation development, the concept of open innovation, cluster concept, the concept of national innovation systems, the Concept of Triple helix and the model of the Quadruple helix. Relevance for education: Universities must become a centre that creates the conditions and an enabling environment for knowledge management, technology transfer and educational programs, the formation of the digital identity of graduates, and the digital transformation of society.

Keywords

Industry 4.0, university ecosystem, innovative platform, digital transformation.Introduction

1. Introduction

The World Economic Forum in Davos has become a platform to discuss the challenges of global economic, political and human change, which are indicators of the Fourth Industrial Revolution and the Industry 4.0 strategy. Innovation, flexibility and adaptability to change are key drivers of growth and value creation in the Fourth Industrial Revolution. The essence of these changes is that today's material world merges with the virtual, creating new cyber-physical complexes combined into a single digital ecosystem.

According to the Reskilling Revolution strategy [1], 133 million new vacancies will appear in the country's leading economies by 2022. One million people need to be trained and retrained by 2030, due to changes in 42% of basic skills soon. As the skills required in the labour market change rapidly, lifelong learning should become a vital need for Industry 4.0.

ICTERI-2021, Vol I: Main Conference, PhD Symposium, Posters and Demonstrations, September 28 – October 2, 2021, Kherson, Ukraine
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Nowadays, higher educational institutions of developed countries have become the most crucial infrastructure for the innovative development of states; have acquired strategic importance in forming intellectual capital. Education level is one of the three components of the Human Development Index, GDP per capita, and life expectancy. According to [2], opening each new university increases the country's GDP per capita by an average of 0.05%. It increases the volume of the economy of the region where the university is located by 0.4%.

Education and human capital development are essential for rapid and sustainable growth in Ukraine, but human capital in national wealth remains small. Ukraine ranked 42nd among 64 countries in the IMD 2020 World Talent Competitiveness Ranking [3], ahead of developed European countries. According to World Bank estimates [4], human capital in Ukraine accounts for only 34% of total national wealth, while in Europe and Central Asia – 62%. These data indicate that the role of Ukraine's human capital as a driving force for economic growth remains relatively weak and has little effect on economic growth due to the low level of digital competitiveness. Ukraine ranked 54th in the World Competitiveness Ranking in 2021 among 64 countries [5].

The Education 4.0 Forum [6] aims to accelerate systemic change by mobilizing stakeholders around new models for transforming the future of education. Education 4.0 is based on the development trends of Industry 4.0, digitalization of educational institutions and leading teaching and learning practices using ICT. The integration of Industry 4.0 trends into engineering curricula is becoming one of the top priorities of universities and academic institutions [7].

The acceleration of technology and the information explosion have created an urgent need to rethink the education system, traditionally based on educational material. The requirements of Industry 4.0 make it necessary to enrich the academic program with interdisciplinary constructs that will teach students to think, learn to synthesize information and think critically. The concept of Society 5.0 (Super Smart Society) [8], which aims to modernize society and the economy through human capital, should adapt people to live in a world of digital technology and big data.

Thus, the relevance of adapting Education 4.0 to the requirements of Industry 4.0 is obvious. Therefore, the article aims to substantiate the concept of an educational paradigm based on the principles of the innovative digital educational ecosystem in the globalization of the world economy and European integration aspirations of Ukraine by Industry 4.0 and Society 5.0. The authors consider the following tasks to achieve the research goal:

- to analyze the digital trends of Industry 4.0 and their impact on the development of digital competencies of people;
- to explore the models of industrial ecosystems with their implications for transformation in education;
- to identify trends in the development of Education 4.0 and develop a model of the innovative educational ecosystem;
- to consider examples of successful implementation of innovative educational ecosystems in Ukraine.

2. Analysis of Related Research and Publications

Many scientific and practical works of domestic and foreign researchers are devoted to the problem of the digital revolution for the digital transformation of the economy, the development of Industry 4.0, the development of human capital as the national wealth of Ukraine, the formation of digital skills and competencies. Klaus Schwab first explored the phenomenon of the Fourth Industrial Revolution in [9]. Analysis of key areas of technological change and innovative models in the industry under the general name "Industry 4.0" was carried out by foreign and domestic scientists, in particular, Hermann M., Pentek T., Otto B. [10], Matviychenko O.S. [11]. Sigida L.O., Bondarenko A.F. [12]. Analytical review "Landscape Industry 4.0 in Ukraine" presented Ukrainian innovators of Industry 4.0 [13]. A detailed analysis of the Industry 4.0 development strategy is given in [14, 15]. The digital transformation of the economy and society requires an analysis of the educational sphere of Ukraine, the study of which is carried out in a review by the World Bank Group [4].

Many foreign and domestic scientists, including G. Vasiliev, N. Gladchenkova, Y. Kolyutkin, L. Novikova, P. Lerner, M. Lyakh, M. Sokolovsky, and others have devoted their research to the

substantiation of the concept of an "innovative educational environment" and the formation of such an environment in higher education institutions. Tsyunyak O.P. [16] analyzed the idea of an "innovative educational environment" and its structural components. Researchers such as Moor, J. F. [17, 18], Quan, S.J., Wang, Yu.L. [19], Kleiner, G.B. [20], and others analyzed the educational environment as an educational ecosystem.

Modern studies of the synergy of Education 4.0 and Industry 4.0 are discussed in [21,22]. The author of [21] notes that education systems that cannot grow at the same rate as the industry evolves limit access to the skills needed to develop a prosperous economy and negatively affect global productivity. The work [22] presents the Industry 4.0 branch competitive centre ecosystem, which unites "the Educative Company, Educative program for Industry 4.0 direction, company intellectual property, norm base to prepare the specialists". The aligned structure of Industry 4.0 with Education 4.0 is the way forward for all levels of education. The authors define the need to form students not only "hard skills, such as technology design and data analysis, but also noting the crucial need to foster human-centric skills – cooperation, empathy, social awareness and global citizenship".

STEM technology (Science, Technology, Engineering, and Mathematics) is one of the ways to address the challenges and needs that arise before Industry 4.0. The American STEM Education strategy [23] defines the main directions for the implementation and use of STEM technologies as a scientific and technical potential that determines the country's economic development STEM education and information technology are tools for adapting to the digital transformation of the world's economy. The impact of STEM education on the formation of skilled professionals with 21st-century skills required by Industry 4.0 is considered in [24].

At the same time, there are no scientifically substantiated recommendations for forming an innovative educational environment (IEE) as a condition for training qualified personnel for the digital transformation of the economy and society. The IEE model as an educational ecosystem has not been defined, the business model of a modern university as a centre of innovation and entrepreneurship has not been built.

3. Discussion

3.1. Conceptual Basis of Digital Educational Ecosystem

Modern trends in the evolution of the economy and society: globalization, urbanization, digitalization, intensification of international competition, artificial, social and environmental problems made it necessary to search for answers to these challenges. Over the past decade, various countries have been developing national strategies for innovative development, focusing on the introduction of advanced digital technologies: in Germany, it is the Industry 4.0 strategy, in the USA – the Industrial Internet, in Singapore – the Smart Nation, in China – "Made in China", in Japan –"Society 5.0."

3.1.1. Digital Trends of Industry 4.0 and their Impact on Education and Society

The development of digital technologies is changing the modern world and attitudes in it. Trade, information exchange, and ordinary human contacts are increasingly becoming digital, blurring the boundaries between nations and realizing the idea of a digital society and a global digital economy. A new approach to production, based on the mass introduction of information technology in the industry, large-scale automation of business processes and the spread of artificial intelligence, known as "Industry 4.0". Digital trends that determine the digital transformation of the economy and society and are based on information and communication technologies are as follows [25]:

- Development of the Internet of Things, and Internet of Bodies;
- Application of Artificial Intelligence Technology and Machine Learning;
- Big Data Analytics, which become the primary source of competitiveness;
- Digital transformations of both individual businesses and entire sectors (Digital Transformation Implementation);
- Economics of sharing (Data Sharing Technology);
- Virtualization of physical infrastructure IT-systems (Virtualization of IT systems);

- Distributed Blockchain Technology;
- Visual and voice search services;
- Cloud computing, Grid computing, and Quantum computing);
- Autonomous Robotic Systems Technology and Robotic Process Automation Technology;
- Human-Machine Interface Technology.

The Industry 4.0 strategy expands on the Japanese human capital development strategy "Society 5.0". This strategy should "solve economic and social challenges and create new values through the effective use of IoT, Big Data and AI., which enable harnessing human creativity and creating a new society of the future using cutting-edge technologies" [26].

Let us consider in more detail the impact of major digital trends on the digital transformation of the economy for the development of Society 5.0 and human capital and the formation of competencies required for Industry 4.0 (Table 1)

Table 1

Industry 4.0 Education Requirements

Digital trend	Implementation of the direction in Industry 4.0	Required competencies of university graduates
Internet of Thing	Smart equipment, intelligent cars and offices, smart homes, smart cities and more	University graduates must be able to apply the obtained theoretical knowledge and practical skills in the modelling, design, development and maintenance of automation systems, managing them and integrating them into information technology systems using modern microprocessor technologies, applied software and communication technologies.
Artificial Intelligence Technologies	Modern functionality of artificial intelligence and machine learning tools use for speech, gesture and image recognition, medical and technical diagnostics, content and financial analysis, document management and spam detection.	University graduates must be able to extract data, machine learning, computer vision, pattern recognition and natural language processing.
Robotic technologies for process automation	Application of robotics in manufacturing, trade, transport, health care, rescue work, education, agriculture, military affairs, in the form of cobots (collaborative robots that can work with people), drones, mobile and medical robots	The ability to solve problems of production automation, creation of new automation systems based on intelligent robotic systems, use control systems and devices on microprocessors and microcomputers, automated technological systems, computerized administrative, social systems and computer networks
Big Data	Structured or unstructured data sets of large volume are characterized by Volume, Velocity, Variety, Veracity, Variability, and Value. They are used for statistics, analysis, forecasting and decision-making.	The ability to store, process and provide access to big data, to analyze big data; search for possible patterns in the data set; predict trends based on the data received

According to the World Economic Forum research, the development of the Internet of Things (IoT) can affect global sustainable development goals [27]. Today, the Internet of Things is a communication network of intelligent objects (things) that are equipped with appropriate technologies for interacting with each other and with the environment, designed to collect and process information coming from the background, exchange knowledge and perform various actions depending on established scenarios. According to experts, the base of active connections to the Internet of Things will reach 21.5 billion units by 2025 [28].

"Internet of Things" specialization at Lviv Polytechnic, which is created on the initiative of the Lviv IT Cluster, is an example of successful cooperation between universities and the IT industry. As a result, the students acquire knowledge and skills in IoT security, cloud computing, data analysis, automation, embedded systems, M2M technologies, machine learning and the like.

The contribution of AI to the global economy is estimated at 15.7 billion US dollars by 2030 [29]. The Government of Ukraine approved the concept for developing artificial intelligence in Ukraine until 2030 [30]. The main directions of the concept are:

- improvement of secondary, higher education and advanced training to train qualified specialists in the field of artificial intelligence;
- stimulating research in this area, including through grants;
- increasing the level of cybersecurity and improving legislation in this area;
- use of artificial intelligence technologies in the field of defence and public administration etc.

The Ministry of Digital Transformation of Ukraine has developed a catalogue of educational programs for applicants with information on the training of specialists in artificial intelligence [31]. Within the Global Logic Education initiative framework, based on the Faculty of Computer Science and Cybernetics of the Taras Shevchenko National University of Kyiv, a master's program of dual education in artificial intelligence was introduced as an educational ML-laboratory of neural networks was opened. The most common products being developed in this lab are virtual voice assistants, search engines, chatbots and video surveillance systems for crime prevention. Masters and graduates have an excellent opportunity to gain practical skills in software development and conduct postgraduate studies under the guidance of experienced employees of the company.

According to the World Economic Forum, the share of robotic world production reaches 29%. According to the research company ABI Research forecasts, the robot market by 2030 will reach $ 277 billion [32]. Service robotics is booming, factories are adopting innovative work, and AI machines are helping industrialists save 15% to 90% on operating costs. Despite the intellectual potential, research base, and extensive robotic education system for children and adolescents, there is a low level of robotisation in the Ukrainian industry. Industry 4.0 requires education to train specialists with a high level of computer, electrical and system-technical training.

The research laboratory of mechatronics and robotics of the Odessa National Academy of Food Technologies, based on which the south training centre of the Italian company Camozzi, a leading global manufacturer of industrial pneumatics, was created, is an example of successful cooperation between universities and companies in the field of robotics. The laboratory has become a full member of the Association of Robotics of Ukraine, which gives it the right to participate in international competitions among portable robotic systems with artificial intelligence. The Kyiv Smart City team, the Socrat STEM centre, and the 2D3D technical partner have created the First League of Technical Challenges in Ukraine to hold a robotics competition to increase the interest of young people in the exact sciences and modern technologies [33]

3.1.2. Ecosystem Approach to the Digital Transformation of Ukraine's Economy

James Moore defined ecosystems as dynamically evolving communities composed of players from different sectors who jointly develop competencies around innovation, with which they work in a cooperative and competitive logic. The concept of ecosystems allows us to consider interconnections and relationships between the constituent components. A business ecosystem is a network of different organizations involved in the provision of a particular product. Each member of the ecosystem influences and is affected by others, constantly creating evolving relationships or services through

competition and cooperation. Education as a social system is an organic, complex and holistic system. All factors (educational institution, scientific and pedagogical staff, education applicants) are organically linked, demonstrating consistency and contradictions, dynamic balance and imbalance. The socio-economic ecosystem is a localized complex of organizations, business processes, innovative projects and infrastructural formations, capable of long-term independent functioning due to the circulation of resources [34].

APPAU's expert, with the support of OBSE, has developed the national strategy Industry 4.0 in December 2018 [35] as the innovative business ecosystem. The model of the innovative ecosystem of high-tech industrial technologies of Ukraine is presented in Figure 1.

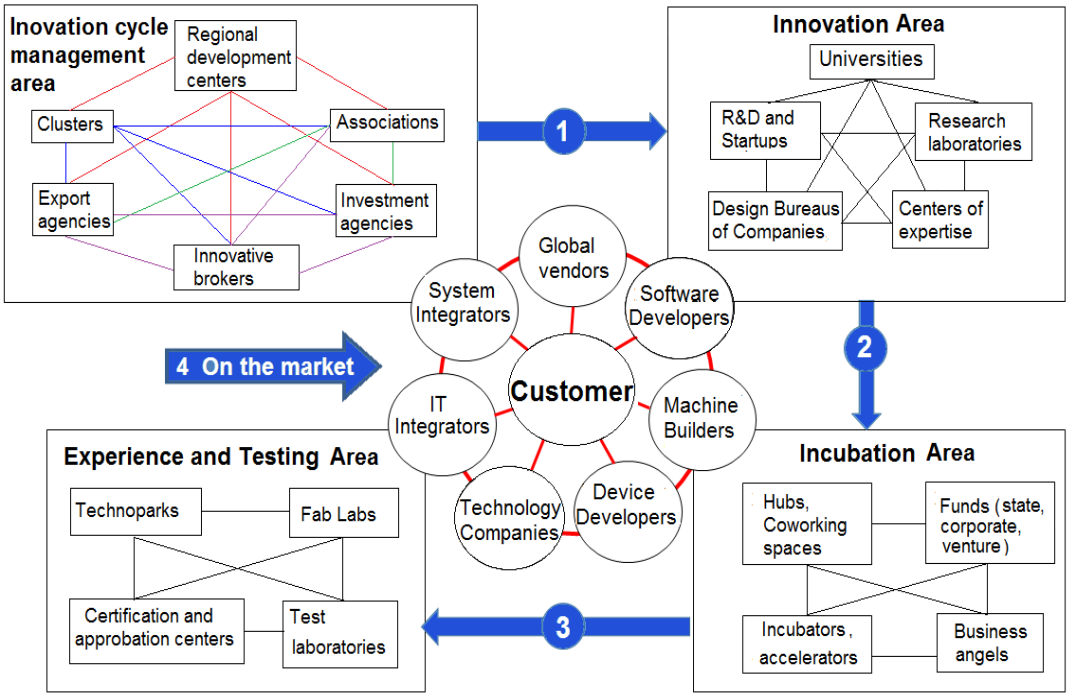

Figure 1: Model of the innovative ecosystem of industrial high-techs of Ukraine (adopted from [35])

The composition and functions of the elements of the national ecosystem of industrial innovation are as follows:

- the area for managing the innovation cycle includes various clusters and associations, development, innovation and investment agencies;
- the area of innovators includes organizations that usually generate innovations: universities, laboratories, design bureaus of large companies, research institutes or startups;
- the incubation area includes organizations that create opportunities for incubation and acceleration of innovators: incubators and accelerators, informal private investors (business-angels), various foundations, donor organizations, etc.;
- the area of experience and testing is the ultimate for rapid approbation and release of innovations to the market. It includes organizations that facilitate the rapid testing, approbation and certification of new innovative products and solutions.

As of 2020, only the IT industry of Ukraine meets the requirements of the Industry 4.0 strategy. Thus, there are 20 regional IT. Clusters, 8 IT associations, 10 IT. Incubators and IT accelerators, 50 HUBs, 19 venture funds, four technology parks, more than 100 R&D centres in Ukraine [36]. In addition, many coworking spaces serve as development centres for young startups. However, these ecosystems, involving the best young talents of Ukraine, in the vast majority work not for Ukrainian customers but global markets.

To implement the concept of digital economy and society, the concept of artificial intelligence in Ukraine, Ukraine's sustainable development strategy until 2030, requires qualified personnel who will meet the market's needs and constantly adapt to rapidly changing world technologies.

3.1.3. The Concept of a Cluster Model of Education in Ukraine

A significant lag in Ukraine in the development of education, applied science and the commercialization of scientific results indicates the need to create production, educational and scientific centres aimed at integrating education, science and high-tech business, particularly the IT industry. The need to develop new mechanisms of interaction between education and the sphere of production, as the situation in the market of educational services does not correspond to the position in the labour market. Educational-production cluster can be an organizational form of interaction between educational and industrial institutions.

Clusters are complex dynamic network-type systems where legally independent partners develop interactive, cooperative relationships. The authors propose considering the educational-production cluster as "a network of interested social partners to develop and test innovations related to the continuous polytechnic, technological education to train future professional personnel for strategically significant and science-intensive industries in the city and region" [37].

The main goals of such a network partnership are:

- minimizing the cost of developing an educational product;
- maximizing the quality of the educational product;
- attracting highly qualified personnel to participate in the educational process;
- project-oriented training following the technological process of the companies participating in the cluster for the rapid adaptation of university graduates to the production process of enterprises.

The cluster implements a universal collaboration model known as the Triple Helix model as an open community of autonomous, geographically close and functionally different partners [38]. Collaboration is understood as a mechanism of interaction when the cooperation participants constantly exchange knowledge, mutually use their assets, and coordinate their decisions. This mechanism is called "collaborative governance". The principle of collaboration is represented graphically as a triple helix. Thanks to the continuous interactions of the state, science (universities) and business in the cluster system, new knowledge are accumulated, which is disseminated in the course of communications between all economic agents, gives the system integrity and dynamic stability. The better the network partner environment is developed, the more local triple spirals are formed in it, the higher the innovative potential of the national economy and the wider its opportunities for sustainable self-development.

The functional intertwining of science, business and government in the triple helix model generates two effects: reducing uncertainty in decision-making by increasing the adaptability of network participants to continuous changes in the environment and constant creation of new entities and knowledge. Thus, a unique synergy of competitive gains arises in network structures, indicated by M. Porter's cluster concept [39].

As current global challenges grow at an accelerated pace, this requires new participants in the innovation process. Unlike triple helix collaborations, a quadruple helix collaboration has a fourth helix to stand on – civil society. This cooperation could provide faster knowledge exchange and allow a better and more sustainable solution to prosper faster. The most crucial system-forming element is the resource of knowledge, which is transformed into innovation and know-how, and implemented in society and the economy. Thus, the Quadruple Helix model visualizes the collective interaction and exchange of knowledge within education, economic, political, and civil society [40, 41].

Paired formats of communication, where the state is present as a permanent participant, currently prevail in Ukraine. Business and science build their relations not directly but indirectly through departments and officials. As a result, the development of the innovation process and diversification of the economy are blocked.

3.2. Education 4.0 and its Implementation as Innovative Educational Ecosystem

The current pace of informatization, the widespread digitalization of the education system and the transformation of its paradigm lead to changes in the approaches to learning. The rapid trends in education and the active development of new information and communication technologies actualize

integrated approaches to learning. The fourth industrial revolution, which introduces artificial intelligence and cyber-physical systems into human life, requires a transformation of the education system today. When entering the labour market, most secondary school students will be doing jobs that do not yet exist. In such conditions, skills become vital, which must be formed according to Industry 4.0. The Education 4.0 forum, initiated by the Platform of the World Economic Forum 2019 to shape the future of the new economy and society following the requirements of the fourth industrial revolution, proposed systemic changes to the development and implementation of promising models of quality education. Report of World Economic Forum 2019 identified eight key findings for shaping education 4.0 models: «global citizenship skills, innovation and creativity skills; technology skills; interpersonal skills; personalized and self-paced learning; accessible and inclusive learning; problem-based and collaborative learning; lifelong and student-driven learning» [6].

The implementation of these critical characteristics of Education 4.0 should provide students with the following opportunities: to study at different times in different places; use tools, adapt to the student's capabilities; use various forms of learning, in particular, inverted classrooms and BYOD (Bring Your Own Device); participate in real and personally meaningful projects; apply tools, that will assess the capabilities of students at every step; determine the content and duration of training courses; choose a mentor; develop interpersonal and critical thinking and a creative approach to work.

The future of economic growth largely depends on qualified engineering staff, whose training should begin at the secondary school level. It then should continue in colleges and universities through the support and active introduction of STEM education. STEM education can be considered a universal model for high-quality preparation of schoolchildren and students for professional activities in Industry 4.0. STEM education implements the following tasks [23]:

- increasing interest in science and technology;
- application of the acquired knowledge in real life;
- development of critical thinking;
- increasing interdisciplinary links through integrated learning;
- building self-confidence;
- developing teamwork skills;
- introduction of innovation.

The essence of STEM learning is a complex study of scientific, technological, engineering, and mathematical disciplines. Modern information and communication technologies motivate students' educational, research, intellectual and creative activities, developing their cognitive interest and forming subject competencies while creating appropriate conditions for developing specialized training. If innovative, artistic disciplines are included in STEM education, particularly industrial design, architecture and industrial aesthetics, this leads to STEAM education.

The authors propose an ecosystem approach to education, taking into account the requirements of Industry 4.0, the principles of Education 4.0, STEM/STEAM approach to teaching and the strategy of Society 5.0. The implementation of this approach may demonstrate greater effectiveness compared to traditional hierarchical models. The authors define the following quantitative targets for the digital transformation of the education system into an innovative educational ecosystem:

- ensuring financial stability and diversification of sources of funding for the university through improved resource provision and diversification of the income structure;
- growth of university revenues as a result of the development of economic independence, investment attractiveness and responsibility of the university;
- improving the quality of admission to a higher educational institution and increasing the number of the university contingent as a result of reforming the content and management of educational processes and generating innovative educational ideas and solutions in the context of global cooperation;
- increasing scientific and educational contribution to the sectoral and regional economy due to the efficiency and effectiveness of research activities in critical areas;
- • improvement of indicators of innovation activity due to technology transfer and interaction with Industry 4.0;
- improving PR activity and presence in the international information space by increasing the Hirsch index, the number of Scopus, Web of Science papers, income from the research;

- development of adaptive, practice-oriented and flexible educational programs and networking with leading domestic and foreign organizations;
- improving the quality of research and human resources;
- improving the quality of the university's service functions for students and staff to world standards through the digitalization of all internal processes and an increase in the efficiency of the management system;
- involvement of public and business associations and representatives of employers in the management of the development of universities;
- creating an orderly campus following world standards;
- increasing the level of internal operational efficiency.

The criteria for assessing the quality of educational programs developed by the National Agency for Higher Education Quality Assurance should be considered as indicators of the effectiveness of the educational process and interaction with the industry.

New learning formats in the innovative educational ecosystem use digital technologies based on artificial intelligence methods. The authors propose to adapt the curriculum to the abilities and capabilities of students using appropriate means of information and communication technologies. For example, interactive intelligent textbooks will be equipped with built-in artificial intelligence. Business games and business cases are offered to be used to estimate students' competencies in real-time and form recommendations concerning directions of their development. Students should use intelligent technologies based on ICT and knowledge bases to improve their motivation to learn and work creatively. They will use knowledge-based and ontology-based intelligent recommender systems to build individual educational trajectories. New educational tools, information resources and ICT should empower students to develop the full range of competencies, skills and knowledge and unleash students' creative potential.

The authors based the innovative educational ecosystem on a quadruple spiral model, which integrates the production of knowledge in the form of intellectual capital, creating economic, political, legal, social and information capital. Innovation is a product of such a system. According to the quadruple spiral model, the proposed innovative educational ecosystem consists of the following subjects of interaction: industry, state, education and science, society. The authors present the structure of the conceptual model of the digital innovative educational ecosystem in the form of such components (Figure 2).

As education customers, business companies form requirements for the quality and quantity of specialists and represent the industry. The companies participate in the employment of graduates. The companies as partners of education determine the structure and content of educational programs. The companies as investors use various forms of public, and civic activity in the organization, and management of education, implement a mechanism of external quality control of education.

The state acts as a customer of education by the needs of Ukraine and implements the state policy in education. The state creates legal, financial, material and other conditions for the functioning of education, mainly providing budget funding for the state order for education. The state implements its mission through ministries, including education and science, finance, culture and information policy, digital transformation, etc. The driving force behind higher education quality assurance is the National Agency for Quality Assurance in Higher Education, an independent, permanent collegial body.

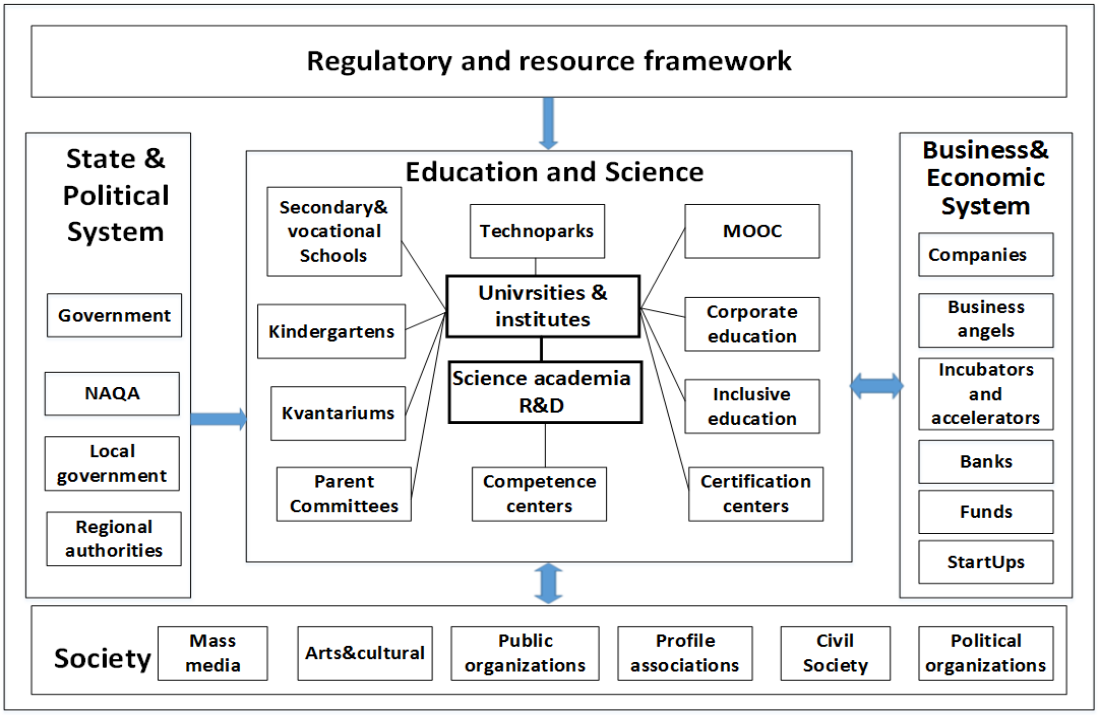

Figure 2: Conceptual model of the digital innovative educational ecosystem

Educational institutions of various levels, including preschools, schools, colleges, institutes, universities, represent education. The primary mission is the diverse development of the child's personality based on identifying his talents and abilities, the formation of schoolchildren and students' desire and ability to learn throughout life, the development of skills for practical and creative application of acquired knowledge.

The National Academy of Sciences, branch academies and R&D centres represents the scientific field. The primary mission is to obtain new and deepening existing essential and applied knowledge in natural, technical, social and human sciences, implementing scientific support for public policy in all spheres of public life.

Profile associations, mass media, cultural, political organizations, public organizations, etc., represent the society. The primary mission is to promote the development and deepening of cooperation between education and industry, collaboration with state and public structures on the development of education and science.

The University 4.0 model is being developed within the cluster model based on the quadruple helix model. The authors believe that the critical elements of University 4.0 should be Industry 4.0, Technology 4.0, Education 4.0, Curriculum 4.0, Student 4.0 and Society 5.0 (Figure 3).

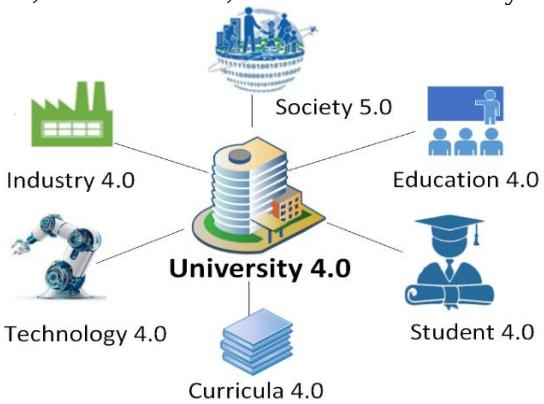

Figure 3: Components of University 4.0

Industry 4.0 is a term for a new era of intelligent manufacturing caused by the development of digitalization and robotics. The central vision of this concept is smart factories that a Cyber-physical system will connect. These factories will use new technologies known as Technology 4.0. Industry 4.0 development trends require new knowledge and skills that will be formed in Education 4.0 through implementing new educational programs Curriculum 4.0. Another living environment has been formed in the modern world. There is digital biosocial space when the virtual space is an extension of the physical and social. The Internet has made students almost independent from teachers in obtaining information and knowledge that they are interested in. Therefore, the educational environment should become Internet-active; it should be attractive to students and adapt to a specific personality, Student 4.0.

To implement the university 4.0 model following the requirements of the digital innovative educational ecosystem, the university itself must become a subsystem of the educational ecosystem. The authors highlight the following activities that the university should focus on:

- creation of a knowledge management system;
- conducting scientific research and cooperation with businesses in the framework of contractual agreements;
- technology transfer and value creation through university research;
- building long-term strategic partnerships with companies;
- design of educational resources for the training and development of students;
- development of information technologies for building individual educational trajectories of students;
- support for academic mobility of students;
- support mentoring and providing intelligence assistance to the student.

To ensure the university's activities, the authors propose a digital model of the university to implement information and communication platforms (Figure 4).

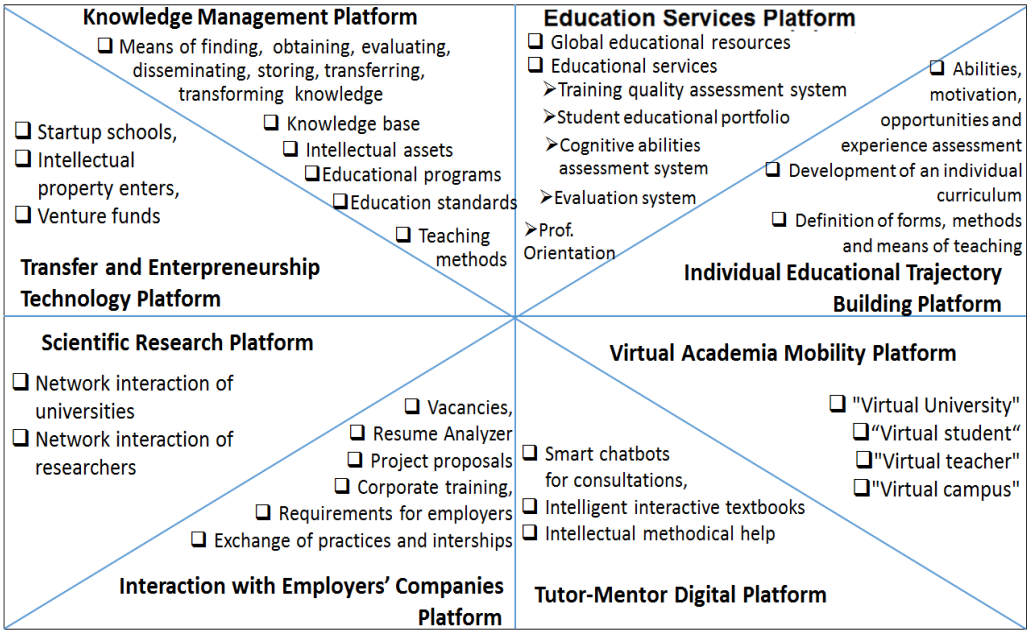

Figure 4: Information and communication platforms of a digital university

The platform for constructing an individual educational trajectory implements information technology to support developing a personal curriculum, the choice of forms, methods and technologies of learning. The educational services platform will introduce information technology to assess the quality of education, form an individual portfolio of student education, assess his cognitive abilities, and determine their professional orientation. The global learning platform will provide delivery of e-learning content. The virtual academic mobility platform will allow students to implement their preferences for studying at partner universities. The platform for the interaction with employers' companies will generate information about vacancies and requirements, offer designer resumes, test

projects for a trial period for employment, corporate training and internships. The knowledge management platform can be based on knowledge management models, for example, the knowledge management model of E. Carayannis with the extension of the architecture of the knowledge production system to the innovation network and knowledge clusters [41].

The digital platform of the educator-mentor will provide an interface for communication in the process of consultations, methodological assistance, individual cooperation, etc. The interaction of researchers will be carried out on a research platform. Technology transfer will take place through a platform for companies to interact. The innovative technology environment platform will support startups and entrepreneurship.

The authors believe that University 4.0 should be transformed into a network university according to the requirements of the cluster model. The organizational structure of the University 4.0 should be modified into a matrix structure with solid horizontal connections. Along with the departments, the educational process is proposed to be carried out in research centres, which can be established as research centres of universities or faculties, or centres at companies with which the university cooperates. Because the University 4.0 model is based on a cluster model, the university must become an innovative business institution.

Achieving the targets set in the strategy for the digital transformation of the educational ecosystem through the creation and implementation of digital tools and technologies for teaching and managing education should demonstrate the effectiveness of the reform. However, the study of the economic efficiency of transforming the education system into an innovative educational ecosystem as a special sector of the national economy that disseminates and produces new knowledge and forms intellectual capital is beyond the scope of this article. The authors agree with the definition of criteria for the effectiveness of educational activities by [42], highlighting economic and socio-economic efficiency, internal and external efficiency, and criteria such as cost-effectiveness, productivity and effectiveness. Cost-effectiveness characterizes efficiency from the standpoint of costs and resources, which should have the lowest possible value. Productivity is the ratio of volumes of products or services with the value of costs for their production, and effectiveness is characterized by the compliance of costs and achieved results to specific goals. These criteria determine the feasibility of investing in the education system, calculate the effectiveness of higher education per unit of average annual costs for higher education, the efficiency of educational institutions, assess the quality of intellectual capital and more.

4. Implementation of Innovative Ecosystems in Ukraine

Innovation Ecosystem Sikorsky Challenge implements the full technological cycle of innovative entrepreneurship: from searching for new ideas to attracting investments to create an innovative product. The Sikorsky Challenge startup school established at the Igor Sikorsky Kyiv Polytechnic Institute is the first innovation ecosystem created based on a university in Ukraine [43]. Innovation Ecosystem Sikorsky Challenge includes Startup School, Business Incubator, Festival of innovation projects, Innovative technological environment "Sikorsky Lab", Centre for Intellectual Property, Venture Fund. Since 2012, more than 100 projects presented at the Sikorsky Challenge have received investment support. The final competition of innovative projects in 2021 was held in 6 sections: Defence and security; Industrial High-tech and space; Green energy and ecology; Biomedical engineering and human health; Agricultural engineering; Information technology, digital country, cybersecurity.

The Corporate university created by IT Company SoftServe [44] for cooperation with the Lviv Polytechnic University Elements can be represented as the educational ecosystem. This university includes:

- Talent Development Centre for talented people who are beginning their career in IT;
- Business School for the advancement of leadership and management competencies;
- Technology school for the development of technical skills and competencies;
- Intercultural communication centre;
- Certification centre from Microsoft, Oracle, PMI, Amazon, Salesforce, iSQI;
- Training excellence centre for teaching management based on international trends and innovations.

One thousand one hundred fifty unique educational solutions, 15000 participants of academic programmes, 5100 graduates, 5300 certificates issued in 2020.

5. Results

The authors hypothesized an ecosystem approach to education for the development of the digital economy and society. Today there are no educational ecosystems in Ukraine. At the state level, the National Industry 4.0 Strategy of Ukraine is considered, which defines the industrial ecosystem as a basis for the development of innovators and innovations in the markets of high-tech industrial segments. As of 2019, only the IT sector of Ukraine meets the requirements of the Industry 4.0 strategy:20 regional IT clusters, 8 IT associations, 10 IT incubators and IT accelerators, 50 hubs, 19 venture capital funds, four technology parks and more than 100 R&D centres. But digital innovation in education is not being implemented. Therefore, it is relevant to create digital educational ecosystems that will ensure individual academic learning trajectories, project-oriented learning methodology based on EduScrum, and relevant competencies for the digital economy.

The authors declare such research results:

- The industrial innovation ecosystem model is examined, and it is shown that only the IT sector in Ukraine meets the requirements of the Industry 4.0 strategy.
- It has been proved that the ecosystem approach to education can manifest great effectiveness and efficiency compared to traditional hierarchical models.
- The components of the innovative educational ecosystem and mechanisms of interaction between its subjects are revealed.
- The conceptual model of the digital education ecosystem based on education and production clusters was created.
- The innovative educational ecosystem model is illustrated by examples of innovative ecosystems Sikorsky Challenge and SoftServe Corporate University.

6. Conclusions

The expediency of changing the educational paradigm by the requirements of Industry 4.0 is substantiated. The digital trends of economic development are analyzed, and the digital transformation of the economy and society are identified — an objective necessity in the development and implementation of a model of the innovative educational ecosystem in Ukraine. The components of the innovative educational ecosystem and the mechanisms of interaction of the subjects of the educational ecosystem, which can be based on educational-production clusters as a universal model of collaboration of complex nonlinear systems, are revealed. The role of universities in the collaboration model as a triple helix model that transforms the university into an innovative business hub is described. The implementation of the innovative educational ecosystem model is shown in the example of the innovative ecosystem "Sikorsky Challenge" and Corporate university created by IT company SoftServe.

Future work aims to develop platforms for the ecosystem under consideration, particularly developing a recommender system for constructing individual educational trajectories for a student, a platform for companies to interact with the department.

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