Analysis of digital technologies in Ukraine: problems and prospects

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Abstract
The article examines the development and diffusion of digital technologies in Ukraine and the EU, and their impact on society and the economy. It highlights the rapid growth and adoption of digital solutions and underlines Ukraine's significant potential for further progress in this area. Key benefits of digital technologies for businesses include market forecasting, process automation, asset monitoring, cost reduction, improved product and service quality, and remote support. However, these benefits are accompanied by risks, such as potential job losses, cybersecurity and privacy threats, and data and human resource quality issues, especially in small and medium-sized enterprises (SMEs). To assess the readiness of Ukrainian SMEs to adopt digital technologies and identify challenges, a survey was conducted. To increase the efficiency of digital transformation, the article proposes the creation of an innovation ecosystem that integrates the interests of all stakeholders. The Digital Innovation Hub model based on the Igor Sikorsky Kyiv Polytechnic Institute is presented as a successful example demonstrating effective collaboration between researchers, educational institutions, SMEs and international partners. This model helps to estimate resource costs and time, minimise development and implementation risks, and respond to customer needs. The systematic approach to combining science, education and business through digital technologies aims to enhance human potential and address economic and socio-economic issues. An increased focus on local digital innovation hubs will help build a national innovation ecosystem and enhance the competitiveness of the country's digital technology sector.

Keywords
digital technologies, education, investments, efficiency, digital innovation hubs, artificial intelligence, digital twins, accounting, ecosystem

1. Introduction

The development of digital technologies is rapidly permeating all areas of social life, exerting a profound influence on the quality and safety of life, the efficiency of processes, and the satisfaction and creation of new needs in society. A review of statistical data reveals a notable proportion of enterprises whose activities are directly related to information and communication technologies, accompanied by a considerable number of employees engaged in this sector. As digital technologies are in a state of constant evolution, there is a need for personnel to undergo continuous training and development to ensure the effective and rational use of these technologies, while also taking into account the potential risks associated with them. The necessity for an increase in the staffing levels of enterprises during digital transformations is confirmed by both Ukrainian and foreign business [1, 2]. A review of statistical data and analytical reviews reveals tangible benefits gained from the implementation of these technologies in business operations, including increased sales volumes, enhanced profitability, reduced expenditure on economic resources and time, and so forth. It is also important to note that there is a significant synergistic effect in related industries and fields of activity. Conversely, the issue of optimising personnel training is becoming increasingly pressing. In this context, it is essential to consider

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the necessity of engaging a unified ecosystem comprising scientific institutions, educational institutions, state institutions, and the business sector. This ecosystem should be dedicated to the advancement of innovations that are essential for economic growth and development, while simultaneously fostering scientific advancement. In order to implement this idea, it is necessary to analyse the existing practice of cooperation between science and business, to identify the problems that hinder this development, and to find ways to solve them. It should be noted that each country has its own particular characteristics in terms of development and the organisation of the socio-economic process. The subject of the research was limited to Ukraine and the countries of the European Union. This limitation is due to the necessity of a rapid and innovative recovery of the Ukrainian economy following the war. According to international ratings, our country has significant human potential, and the European experience of combining human resources, innovation, and business will ensure sustainable innovative development. The purpose of this article is to analyse the current state of development of digital technologies in Ukraine and to determine the mechanism for ensuring sustainable innovative development of the country based on the combination of education, science, and business, taking into account the European experience.

2. Literature review

Many studies by researchers from around the world are devoted to issues of digital technologies. Articles examine the characteristics of the use of digital technologies in education. In particular, Al-Abdullatif and Gameil [3] concluded that students have an unsatisfactory level of knowledge about digital citizenship. Bhutoria [4] argue that there is a need to use AI to personalise education. The transformative impact of artificial intelligence (AI) on tourism, as well as a paradigm shift in teaching methodology and industry practice, is explored in articles by Pencarelli [5], Balula et al. [6]. The positive impact of using augmented reality technology in medical education is noted in article by Dhar et al. [7]. Improving the quality of diagnosis and service in medicine through the use of digital technologies is described by O'Brien et al. [8]. The possibilities of using digital technologies in chemical, engineering and other industries are also presented in scientific studies by Patrón and Ricardez-Sandoval [9], Liu et al. [10], Mogaji and Jain [11]. It should be noted that the final result of any implementation is usually influenced by financial indicators and operational efficiency. The impact of digital technologies on the creation of an effective business, in particular through the creation and maintenance of a customer base, is demonstrated by Skorobogatova [12]. The importance of taking into account the potential of digital technologies for the development of competitive business is proved by Lewandowska et al. [13], Eur [14]. It should be noted that in today's world digital technologies are developing rapidly, bringing both positive results and certain threats. A significant number of scientists identify the problem of ensuring cybersecurity as one of the main threats. In particular, Alcaraz and Lopez [15] analysed the current state of the digital twin paradigm and classified the potential threats associated with it, taking into account its functional levels and operational requirements to achieve a more complete and useful classification. Features of digital threats in the banking sector were determined by Alzoubi et al. [16]. Digital technologies are widely used in agriculture today. Demestichas et al. [17] systematized the advantages of using these technologies in the agricultural sector and presented an overview of the main existing and potential threats to agriculture, providing recommendations for reducing their negative impact.

Digital technologies are associated with the use of Big Data. At the same time, there is a problem of maintaining data confidentiality, which is outlined in the study by Quach et al. [18]. The authors note that marketing research can often lead to interference in people's personal lives when analyzing their preferences. The impact of digital technologies on public life through the provision of information, and the formation of public opinion was considered by Miller and Vaccari [19]. As a result of this influence, it can range from misinformation and hate speech to government interference in online freedoms. At the meso-level, ICTs are typically used by senior management to collaborate and communicate with stakeholders. However, the use of ICT increases the vulnerability of local governments to cyber threats. Cyber threats are on the rise, and local governments are often under-resourced and unprepared, as noted by Frandell and Feeney [20]. Saxena et al. [21] investigated and highlighted the challenges associated with the identification and detection of insider threats in both public and private sector organizations, especially those that are part of a country's critical infrastructure. Researchers have explored the utility of the cyber threat chain for understanding insider threats, as well as understanding human behavior and psychological factors. In a review article by Bécue et al. [22], the opportunities and threats of today's popular artificial intelligence (AI) technology in the manufacturing sector are discussed, taking into account the offensive and defensive uses of such technology. The authors discuss relevant technical, operational, and security issues of using AI.

Digital technologies are inextricably linked to the use of significant amounts of data, as mentioned above. Data quality issues were investigated by Wang et al. [23]. Scientists have identified parameters of data quality, prerequisites, and their impact. The concept of "data analysis competence" is proposed as a five-dimensional formative indicator (i.e., data quality, data volume, analytical skills, domain knowledge, and tool sophistication) and its impact on corporate decisions. The ambiguity of the nature of the concept was investigated by Baur et al. [24] proving the need to take into account many criteria for the selection and analysis of data, as input information for further analysis and decision-making.

In Ukraine, individual works of scientists are devoted to the issue of digital technologies, mainly in the field of educational technologies [25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35]. Practical aspects of the implementation of digital technologies in the production sphere are collected on the platform of Association of Industrial Automation of Ukraine [36]. However, today there is a certain gap between science and practice in the field of development and implementation of digital technologies.

In any case, a person is needed to analyse the results obtained and their further use. This requires constant development and training of a person, both as a developer and as a user. The question of a comprehensive analysis of the market of digital technologies in Ukraine, the assessment of problems hindering their development, and the search for ways to comprehensively assess their implementation require further research.

3. Methodology

The effectiveness of a country's innovation ecosystem has a dominant influence on its competitiveness. That is why not only scientists but also the governments of countries pay a lot of attention to researching the state of innovation development and the factors that hinder it. In the European Union, such work is carried out methodically, based on which new policies and new mechanisms are created to improve the innovative component of the development of both the Community and each country. The European Innovation Scoreboard (EIS) [14] is produced annually and provides a comparative assessment of the research and innovation performance of EU Member States and selected third countries, as well as the relative strengths and weaknesses of their research and innovation systems. This allows countries to assess where they need to focus their efforts to improve their innovation performance. The EIS 2024 distinguishes four main types of activity: framework conditions, investment, innovation activity and impact, with 12 innovation dimensions covering a total of 32 indicators. Each main group contains the same number of indicators and has the same weight in the final innovation index. According to the 2024 report [37], the top 5 countries are Switzerland, Denmark, Sweden, Finland and the Netherlands. Most EU member states improved their scores between 2016 and 2024. Ukraine is also included in the innovation rating, positioned as a new innovator, but with an index score below the average for new innovators and a significant gap compared to other EU countries. Ukraine's strengths in this rating include broadband penetration and a relatively high level of employment of the population in science-intensive activities, but the implementation of innovations is weak, especially in terms of the number of SMEs introducing innovative products and innovations in business processes. The analysis of the dynamics of the components of the innovation index in Ukraine for the period 2017-2024 indicates a high export orientation of domestic innovative activity. In particular, exports of knowledge-intensive services, trademark registrations and venture capital expenditure have increased over the period analysed, while exports of medium- and high-tech products, the number of doctoral students, including foreign students, and government expenditure on research and development in the public sector have decreased. These trends can be partly explained by the effects of the war and the reorientation of the needs and costs of the national economy, the risk of foreign entry, etc. However, the diffusion of scientific achievements in the international scientific space is positive, in particular, scientific publications by Ukrainian scientists are among the 10 % most cited.

One of the components of the innovation index is the digitisation indicator [37]. According to this indicator, Ukraine ranks 12th in 2024, which is better than the average of EU countries. These results indicate the potential of our country for the spread of digital technologies in the country's economy, including the need to combine science, business, and education. Training of relevant specialists and introduction of scientific developments into business will allow to increase the level of competitiveness of our country, which is becoming more and more important in the conditions of post-war reconstruction of the country.

The Ministry of Digital Transformation of Ukraine has developed a methodology for assessing the digital development of regions based on the definition of the Digital Transformation Index of Regions [38]. The calculation of this index takes into account the following directions (sub-indexes): institutional capacity of regional state administrations; Internet connectivity; development of centres for the provision of administrative services; use of "paperless" mode; digital education; business card of the region; penetration of basic electronic services; digital transformation of industry. Accordingly, each sub-index consists of a number of smaller indicators. According to the results of the study, the level of digital literacy "basic and above" will increase from 47.0% in 2019 to 52.2% in 2021. However, there is still an unmet demand in society for more initiatives to promote such skills, as 11.2% of respondents said they had no digital skills at all. The national average of the sub-index "Digital literacy" is 0.460 on a scale of 0 to 1. It should be noted that the level of this indicator is uneven across the regions of Ukraine. The assignment of Kyiv to the Kyiv region and the calculation of standardized indicators in the methodology of the Ministry of Digital Transformation led to the fact that Kyiv is not a leader. Dnipropetrovsk, Lviv and Poltava regions are among the top three according to the 2023 results.

Ukrainian companies whose activities are related to digital technologies were selected for further in-depth research. The analysis of statistical and analytical data showed that artificial intelligence (AI) and digital twins are the most promising. Taking into account the need of service consumer companies to have available information about the offer of services with the use of digital twins and artificial intelligence, the evaluation of such information was carried out by reproducing the scenario of user behaviour, namely by interacting with the search engine. The search queries were "digital twins", "digital twins in Ukraine", "digital twins in the manufacturing industry", "digital twins in the oil and gas industry", "digital twins in agriculture", "digital twins in logistics", "digital twins in engineering", "digital twins in equipment maintenance", "digital twins of a technological process", "digital twins in construction" and similar phrases with the words "artificial intelligence". The Ukrainian language was chosen for the survey as a factor in orienting service providers to the local market. As a result of the data collection, some internet resources were obtained in which the technology of digital twins and AI are mentioned.

Also, on the basis of the catalogue of Ukrainian enterprises created by the YouControl service [39], it was determined that as of April 30, 2024, 328228 business entities were operating in Ukraine (27948 companies and 300280 individual enterprises), including, in particular, information technologies. Based on our catalogue of digital services market participants in Ukraine and with the participation of members of the Ukrainian Cluster Alliance [40], with the help of APPAU [36], within the framework of the implementation of the international cooperation project "Digital Transformation of SMEs in the Eastern Partnership Countries", with the financial support of the German government, a survey was conducted. Based on the analysis of scientific works and the participation of experts in this field, a questionnaire was developed. The purpose of the survey was to find out the level of penetration of Industry 4.0 technologies in production enterprises of Ukraine, including APM technologies; to clarify the state of application of digital technologies – management of production assets, advanced production planning, digital twins, MOM and ERP systems; to identify the main obstacles in the penetration of new technologies. An online survey method was used. The target group are representatives of manufacturing companies, managers of production automation departments. The survey period is from 25 February to 4 April 2024. Of the companies that responded to the survey, 40% were system integrators, 29% were customers – users of digital technologies, and 26% were complex engineering and technology developers. In terms of industry, the respondents also represented different sectors: mechanical engineering (SQ 006) – 34.3%, energy (SQ 012) – 28.6%, engineering (SQ 003) – 20.0%, food and processing (SQ 001) – 11.4%, agriculture (SQ 014) – 8.6%. The results of the survey allowed to identify the main problems of the development of digital technologies enterprises and to suggest ways to solve them. A critical analysis of the scientific works of domestic and foreign scientists and the EU regulatory framework made it possible to identify possible ways of increasing the efficiency of innovative activity in Ukraine, in particular through the creation of an innovative ecosystem involving science, education, business and state institutions. Center 4.0 KPI DIH was defined as the basic model of the innovation ecosystem, which will contribute to the establishment of interregional cooperation for the formation of a single Ukrainian industrial innovation ecosystem, fully connected and synchronised with the vision and challenges of the European Union.

4. Results and discussion

4.1. Overview of the development of digital technologies in Ukraine

The World Economic Forum predicts that 70% of value creation in the next decade will be based on digital platform business models [41]. Statistical data shows a rapid increase in the proportion of businesses using digital technologies (figure 1).

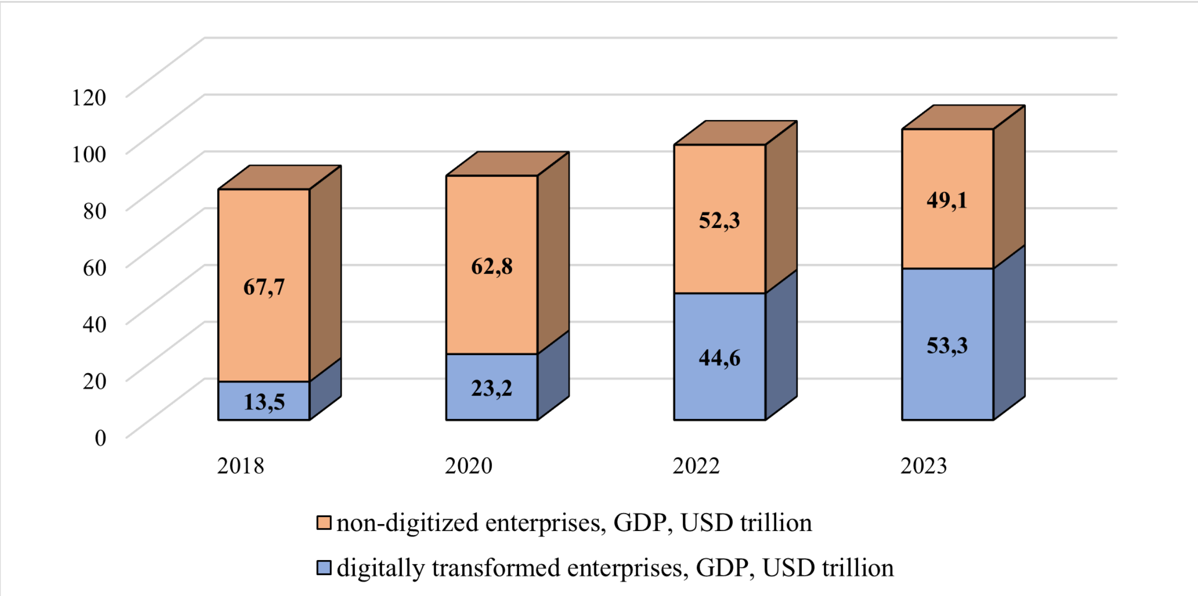

Figure 1: Digitally transformed enterprises in global GDP, 2018 – 2023 (built on data by Krupianyk [42]).

In Ukraine, too, the level of digitalisation is developing rapidly, both in the economy and in education, the provision of administrative services and other areas. When analysing the business environment, we looked in particular at the number of business units whose activities are related to digital technologies, according to data from the YouControl service [39]. Kyiv, the capital of Ukraine, is the leader in terms of the number of active business entities in this segment. In total, Kyiv and the Kyiv region account for more than 30% of the total number in Ukraine (figure 2).

A similar situation is observed in terms of the number of enterprises in the regional section – Kyiv and the Kyiv region account for 55 % of the total number in Ukraine (figure 3).

The analysis of the digital technologies used in terms of their degree of innovation and prospects for further development has identified two priority directions – artificial intelligence and digital twins.

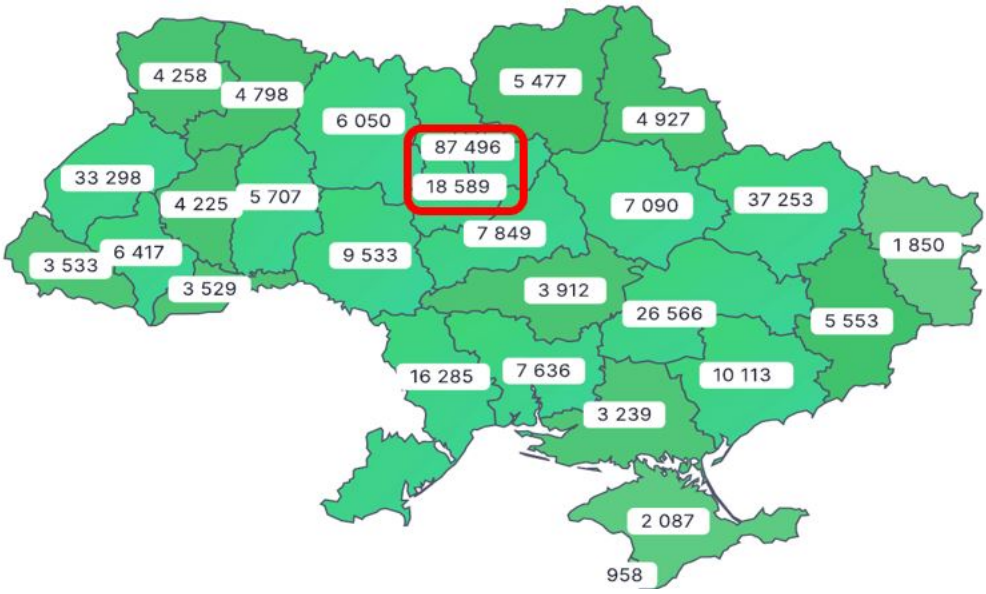

Figure 2: Entities of entrepreneurial activity of Ukraine engaged in information technologies (built on data [39]).

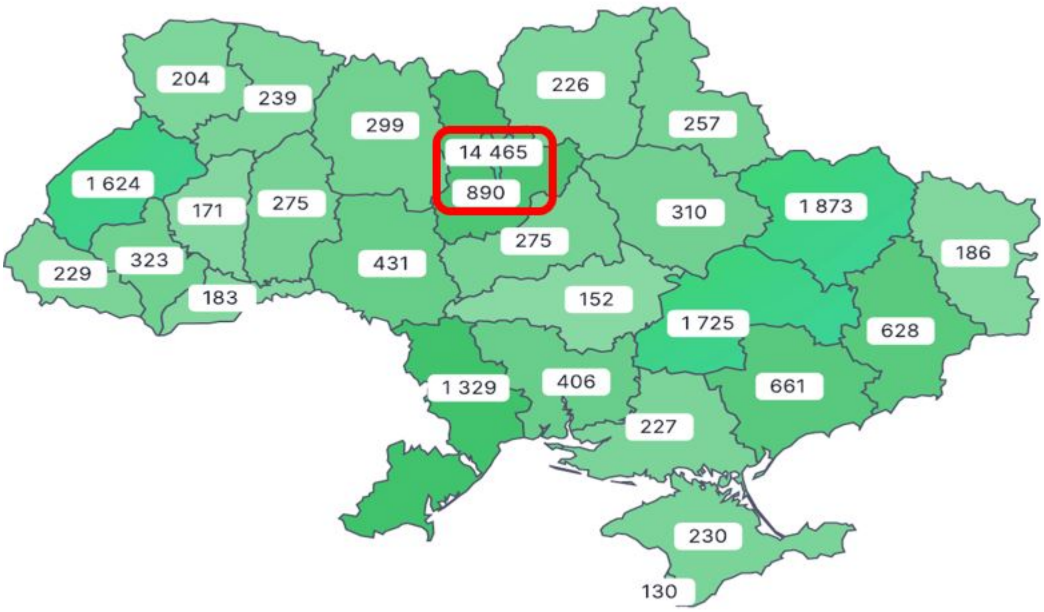

Figure 3: Domestic enterprises engaged in information technologies (built on data [39]).

In the manufacturing sector, digital twins are considered to have significant potential for improving efficiency and optimising processes. They can provide the ability to continuously monitor and diagnose the condition of equipment in real time, allowing operators to quickly identify anomalies and prevent accidents. In addition, by analysing the data obtained from digital twins, it is possible to predict future failures and maintenance needs, which helps to optimise maintenance planning and reduce production downtime.

Another important benefit of digital duplicates is their ability to optimise production processes. By analysing the data from these duplicates, new, more efficient ways of using equipment and reducing costs can be discovered. In addition, digital duplicates allow new processes to be tested virtually without using real resources, helping to speed up innovation and reduce risk.

It is also possible to track all stages of the product lifecycle, ensuring quality and identifying problems in good time. All this makes digital twins an indispensable tool for industrial companies, helping them to reduce costs, increase productivity and gain a competitive edge.

Grammarly and People.ai are among the most popular Ukrainian AI projects. Grammarly [43] helps eliminate grammar and spelling mistakes and improve the structure of text. The service is trusted by around 70,000 teams worldwide. People.ai [44] is a Ukrainian startup built on an AI-based CRM platform that collects and analyses data from sales managers. The platform then makes recommendations to improve sales efficiency. One of the applications of AI is the development of self-driving cars. The author of the startup ROTHEM [45] notes that the project is based on technologies that work in an unmanned car – AI for detecting objects, determining the distance to other cars and predicting dangerous situations on the road. Ajax Systems [46] is also actively using AI technologies in the company's business processes and their automation. A separate team at the company is working on implementing AI technologies in video surveillance systems. Ajax's cameras use AI analytics for detection, which allows them to distinguish between different objects and perform selective recording. The company's marketing team has also started using AI tools in its localisation work, which has already yielded significant results. SoftServe's AI research is conducted by the GenAI Lab. It was developed by SoftServe's research and development department, which employed more than 100 people in June 2023. The role of the research and development is to find a technological solution and sell it to customers. Its main activities are language modelling, product design optimisation and the creation of 3D models from text. According to the head of SoftServe's research and development department, AI is helping to improve the efficiency of IT projects. Increasingly, companies are trying to develop their own tools or license well-known solutions on the market. Moreover, it is not only specialised IT companies and start-ups that are involved in developing solutions using AI. Some retail networks and manufacturing companies are also developing their AI-based projects. For example, the Fozzy Group is developing its neural network, Kissa AI [47]. This is a kind of portal that recognises products and their weight and automatically calculates the cost. This approach can improve the customer experience and customer service. In general, the most common applications of AI in Ukraine are in medicine, energy, education, business, public administration, and the military.

4.2. Problems of the development of digital technologies in Ukraine and ways of their solution

In order to identify problems in the development of this sector, a survey was conducted among IT companies and members of the Ukrainian Cluster Alliance [40]. The results of the survey show that 26% of the respondents do not consider the introduction of digital technologies for the current period, but 51% plan to implement pilot projects in 2024. This situation can be explained by the presence of certain problems in the development of this direction:

- Insufficient awareness of the possibilities of using this technology in production and other business processes of companies – the results of the survey show that a third of respondents are not even familiar with the relevant technologies or their application, and 14% noted difficulties in convincing the management of the necessity. More than 10% of respondents recognise the conservatism of senior management and more than 17% note the resistance of middle management. This in turn leads to a fear of losing resources, with more than 30% of respondents unwilling to take risks in implementing these technologies.
- Staffing – engineering specialists are needed with skills in maths and physics, which are harder to master than the humanities. According to the results of the survey, system integrators (40% of respondents) and end customers – users of digital technologies (29% of respondents) make up a significant proportion of digital technology market players, with developers accounting for only a quarter. As for AI and machine learning, only 6% are developers of this technology. In addition, 43% of respondents recognise the weak skills and knowledge of employees as one of the main obstacles to the implementation of digital innovative technologies in the company. The lack of qualified contractors (integrators, developers) is also cited by 45% of respondents as one of the main barriers to implementing these technologies.

- Insufficient attention is paid to marketing strategy – lack of proper advertising of AI product developers and start-ups, as well as their active promotion on the market, which significantly reduces the circle of potential customers and clients. According to the results of the survey, 20% of the interviewed company managers note the lack of data on a reliable supplier of the specified solutions in Ukraine. It should be noted here that there is a certain lack of trust and openness to the dissemination of information about the innovative tasks of enterprises in a public form to find potential partners. In particular, only 25% of respondents are willing to make data publicly available.
- Lack of financial and other resources for the implementation and execution of projects – AI development projects usually require significant financial costs and the availability of the appropriate material and technical base, which SMEs often do not have. The creation of digital replicas requires investment in technologies for data collection and analysis, modelling and the development of the necessary infrastructure. This can become a serious financial burden for the business, especially for SMEs. According to the survey results, almost 50% of companies consider this to be the main problem.
- The rapid development of digital technologies requires constant monitoring and research, continuous improvement of staff skills, and self-education. This is one of the reasons why 45% of respondents do not consider these technologies relevant to their production and 20% noted the existence of high barriers between different technical services.
- Quality and scope of data for training neural networks – the quality of the initial data set affects the results of AI training, as well as the appropriateness and reliability of the results obtained. According to the results of the survey conducted, more than 30% of respondents do not have the practice of testing technologies as one of the main reasons for refusing to implement relevant technologies. The data itself, which is increasingly being used to make more optimal decisions, taking into account a variety of factors, including non-obvious ones discovered through big data and artificial intelligence, is coming to the fore. Data quality is a critical issue. Incorrectly entered data, manual input errors, obsolescence, inaccuracies or data incompleteness, as well as repetition of the same data in different datasets and a lack of clear data organisation and structure, all impact the effectiveness of analysis and decision making. SMEs need to adopt a data-centric culture.
- Heterogeneity of data – in many manufacturing companies, data can be spread across different systems and platforms, making it difficult to integrate and create a digital duplicate, requiring the involvement of a large number of specialists in different fields and costing time.
- Cybersecurity and privacy issues – The storage and processing of large amounts of data used to create digital twins and also to train AI is a potential target for cyber-attacks. Additional efforts are needed to ensure reliable protection of this data. As digital technologies increase the amount of information stored and processed, ensuring the security of this data becomes a critical task. With each new digital solution, new potential attack vectors emerge for malicious actors. Organisations must comply with confidentiality and security requirements to prevent breaches. Security incidents can lead to a loss of customer confidence and damage a company's reputation. Cyber-attacks can result in financial losses due to data breaches, fines and system recovery efforts. Therefore, SMEs have a vested interest in proactively addressing cybersecurity threats and may require assistance from specialised professionals.
- Regulatory policy – There is a lack of standards and rules for the application of AI technologies, particularly with regard to ethical issues, risk considerations, etc. Companies may also face difficulties in implementing digital counterparts, as current regulations and standards may be incompatible with new technologies or require adaptation. Only a third of respondents have a formalised policy or strategy for the development of digital innovation in production, and another third are in the process of developing one.

At the same time, it is also necessary to take into account the characteristics of the development and use of AI systems, which are determined by their specific characteristics: opacity (the limited ability of the human mind to understand how certain artificial intelligence systems work), complexity, continuous adaptation and unpredictability, autonomous behaviour, functional dependence on data and data quality.

Among the ways to overcome these obstacles, we offer the following, which include technical, socio-cultural and administrative tools:

- A crucial element is employee training and awareness regarding digital technologies and cybersecurity. Awareness of the possibilities leads to strategic planning of implementation, defining specific steps and responsible individuals. This systematic approach ensures efficiency throughout the process. Staff training and cultural change: the implementation of information campaigns and the development of specialised training programmes and courses will help staff to adapt to new technologies and processes. Separately, the importance of a favourable organisational atmosphere in the company to support innovation and the introduction of new technologies should be mentioned.
- Assessing costs and benefits – implementation should be preceded by a comprehensive analysis of the costs and expected benefits over the entire life cycle of the asset. This will help to understand the economic feasibility of implementing the project, determine the optimal level of investment and formulate an investment case.
- Phased implementation and pilots – instead of a large one-off implementation of digital twins, a phased approach can be considered, using pilots to evaluate effectiveness and address any shortcomings before scaling up, significantly reducing risk.
- Standardisation of data and integration of systems: using global best practices for data processing and integration of different systems, the application of standards will standardise the process of creating digital duplicates, thereby reducing costs and ensuring their continuity and accuracy.
- Considerable attention to cyber security: measures and resources to strengthen protection should be considered as an integral part of the company's activities. Working with experts in cyber security and digital transformation can also contribute to successful implementation.
- Partnering with other stakeholders: partnerships with leading technology companies, consultants, educational institutions and cluster associations can help solve complex challenges and provide access to necessary resources and expertise.
- Financial considerations for implementing and supporting digital solutions are essential. EU and Ukrainian grant programmes can play a positive role in promoting the digitalisation of enterprises. At a strategic level, the Ukrainian government is actively supporting this process. For example, the Ministry of Digital Transformation of Ukraine, in cooperation with European partners, including GIZ and the European Commission, is systematically developing the national network of European Digital Innovation Hubs (EDIHs) based on the European model [48]. Participants in this network are committed to providing services to SMEs to support their digitalisation efforts.

4.3. Increasing the effectiveness of the use of digital technologies

During the digital transformation of an industrial enterprise, many technological projects can be implemented that enable and, in some cases, drive the desired transformation. These projects must be able to solve growing problems and achieve the desired results within their objectives and requirements.

For projects started before the adoption of the digital transformation strategy, their scope should be reviewed and, if necessary, adjusted to maximise their impact and contribution to the digital transformation strategy.

Digital transformation is a breakthrough innovation. It opens up new possibilities in business models, value propositions and operational efficiency. Increased competition will force entire industries to transform to become or keep pace with market leaders, while others will experience a loss of market share. As always, such breakthroughs are fraught with risk. The main task in the process of digital transformation is to minimise the risks involved. To do this, we suggest that industry users follow the First Steps to Adoption template shown in (figure 4).

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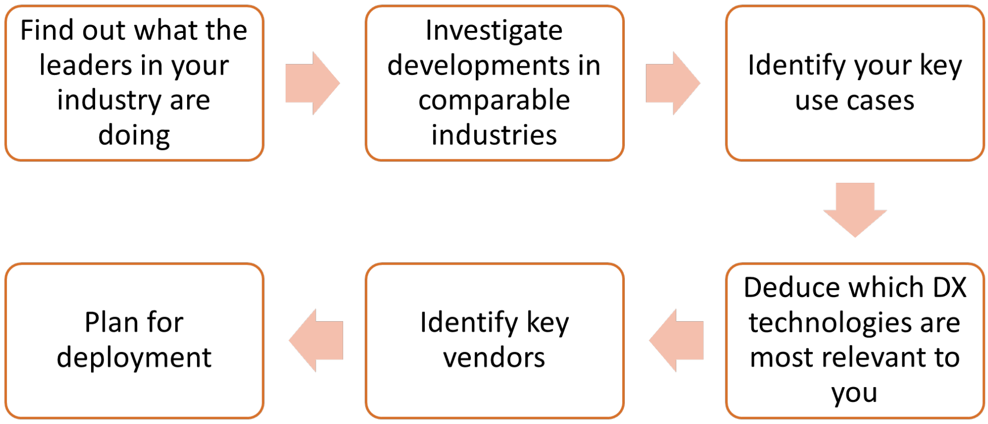

Figure 4: First steps template for adoption [49].

There are many resources to help you plan your next steps, including framework publications and technical publications (such as the white paper Edge Computing in IoT). In addition, the Digital Innovation Hub has test and demonstration benches to help evaluate the process and outcomes of implementation, using a test-before-invest approach.

As noted by domestic and foreign experts and analysts, digital technologies bring significant positive effects in various economic sectors and spheres of social life, but they also have their risks and threats. At the same time, the analysis of existing barriers to their implementation by domestic enterprises conducted during the research includes personnel issues, problems in finding partners, insufficient awareness of technologies, the need for financial resources, etc. Domestic enterprises consider participation in USAID programmes (45% of respondents), their innovative development funds (23%), the Ukrainian Startup Fund (20%) and other sources as possible ways to solve financial problems in the diffusion of innovative technologies. We believe that it is useful to consider projects for the development and implementation of digital technologies from the point of view of the innovation ecosystem, which should take into account all key stakeholders in their responsible use. From this perspective, each stakeholder group will receive a positive outcome from the introduction of digital technologies:

- Citizens – better services in health, education, transport, public services, higher quality products or services, taking into account an individual approach;
- Businesses – increased efficiency of operations, expansion of markets and sales volumes, introduction of new products and services, improvement of staff skills;
- Governments – cheaper and greener services, transparency, less bureaucracy.

As mentioned above, risks and threats should be taken into account when implementing digital technologies. At the level of the company that will implement these innovative projects, we recommend applying the concept of responsible use (figure 5).

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As digital twins and AI are digital representations or software design patterns, existing software development practices and approaches should be used as initial guidelines. We believe it is appropriate to focus on applying the principles used by many software startups, where requirements are unclear, resources are limited, and product/market fit must first be found. This approach used by many startups is called "The Lean Startup". For most domestic industrial companies, the creation of digital duplicates and the application of AI is still uncharted territory. Therefore, the approach originally developed

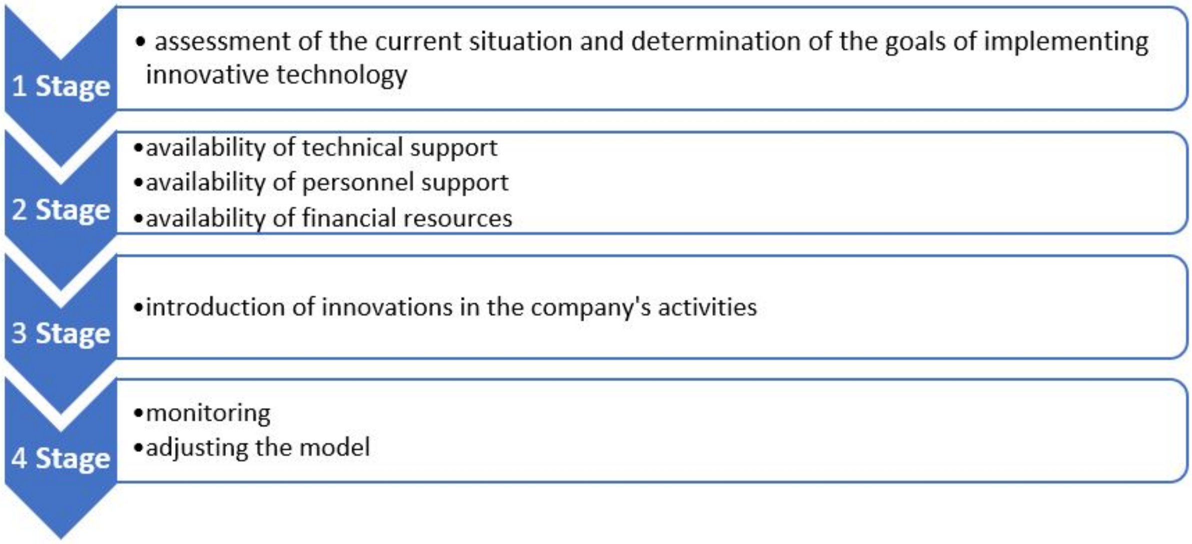

Figure 5: Stages of implementation of innovative technology at the enterprise.

for startups can be useful in guiding the process of developing and implementing innovations under conditions of uncertainty.

After preliminary research into the business needs and the assumption that the application of digital technologies can solve the outlined problem, a one-page description of the solution is created. This description is based on the Lean Canvas described in the Lean Startup Approach section. For example, a canvas can be adapted for a lean digital twin process and called a Lean Digital Twin Canvas. It describes all the key elements of the problem-solution fit.

The procedure for completing the Lean Digital Twin Canvas (for Digital Twin, developed on the basis of [50]):

1. Problem – Identify the top 3 problems your digital twins will solve based on the priority matrix.
2. Customer Segments – Who are the target users who will benefit from the solution? (Digital Twin)
3. Digital Twin's Unique Value Proposition – What makes your Digital Twin different from what you are already doing?
4. Solution – What are the three main functions of the Digital Twin? (AI, real-time working, decision support, etc.)
5. External Challenges – What external challenges can the Digital Twin address (security, data access, connectivity)?
6. Return on Investment – How will this Digital Twin deliver a return on investment?
7. Key metrics – How will the Digital Twin be measured? (quantitative)
8. Integration – What are the basic integrations needed to make this work?
9. Cost – What are the projected costs?

A logical sequence of actions is proposed, the first step of which is the analysis of the problem and the results expected by the users. The advantage of this approach is the identification of tasks, and only then the functions of the innovative product (technology) with which it should be equipped are determined. We believe that this holistic approach takes into account all aspects necessary for the implementation of a successful Digital Twin project.

Based on the analysis and ranking according to criteria important to the performer, a candidate for the digital twin is identified. To test the hypothesis of its usefulness, it is worth creating a simplified version of the layout, demonstrating 2-3 key functions. This will provide a basis for further movement towards the implementation of the project.

A lean digital twin approach is well suited for organisations that are just starting their digital journey and want to use an iterative approach to systematically define requirements while demonstrating business value. This approach requires top-down support and bottom-up involvement. It is a collaborative approach that ensures the sustainability of the process as it is not prescriptive. However, it will take several iterations or changes to find the best fit between the digital twin and the business.

As the results of the survey showed, domestic companies feel an acute need for appropriate staff. In addition, in order to increase the efficiency of the use of digital technologies, it is necessary not only to provide appropriate personnel at the initial stage, but also to train and improve the qualifications of the company's personnel on an ongoing basis. The marketing component should also be taken into account (advertising, deepening the domestic market, entering foreign markets, etc.). In order to increase the level of competitiveness of domestic companies whose activities are related to digital technologies and directly to AI and digital twins, it is necessary to research, develop and implement modern technical solutions. As a rule, SMEs do not have a sufficient volume of financial resources and the corresponding material and technical base for this purpose. In order to solve these problems, we consider it necessary to involve the Digital Innovation Hub (DIH) in order to receive various types of support (technical, advisory, information, etc.). In particular, more than 50% of respondents need help in preparing grant applications, information support (43%) and help in developing detailed business cases for innovative solutions (40%). More than a third of the companies that participated in the survey point to the need for regular seminars and training for business specialists, as well as help in developing their digital transformation strategy. Not to be forgotten is the development of an appropriate legal framework that takes into account the requirements of EU and other partner countries' legislation in the field of the development and use of digital technologies, as well as the creation of targeted state programmes for the development of innovation in the leading sectors of the economy, the need for which is noted by 40% of the companies surveyed.

4.4. Digital innovation hubs as a way of forming the country's innovation ecosystem

The growth in innovation indicators is due to various factors, as shown by the components of the European Innovation Scoreboard [14]. The analysis of statistical data shows that there is a direct relationship between innovation and the economic development of a country. We believe that the development of an innovative ecosystem will allow us to consider a comprehensive approach to the reconstruction of our country. In this context, it is appropriate to implement the European experience, namely the operation of Digital Innovation Hubs (DIH), which are currently being reformatted into EDIH – European Digital Innovation Hubs, whose activities are supported by the European Commission. European Digital Innovation Hubs (EDIHs) are comprehensive centres created to help enterprises respond to digital challenges and increase their competitiveness (32). Such centres are part of regional innovation ecosystems, but also part of the pan-European network. Through their presence at the regional level, EDIHs have information about the needs of local enterprises. They can provide services in their own language, according to their innovation ecosystem. The European coverage of the network facilitates the exchange of best practices between centres in different countries and the provision of specialised services between regions in the same country.

With the support of the EDIH, companies have the opportunity to improve their business processes, production, products or services with the help of advanced digital technologies. Small and medium-sized enterprises gain access to high-quality technical expertise, allowing them to follow a "test before you invest" model that maximises their chances of success. In addition, EDIHs provide innovative services such as financial advice and facilitate the development of skills that are essential for a successful transition to digital transformation. EDIH support enables companies to improve their business processes, production, products or services through the use of advanced digital technologies. Small and medium-sized enterprises gain access to high-quality technical expertise, allowing them to follow a "test before you invest" model that maximises their chances of success. In addition, EDIHs provide innovative services such as financial advice and facilitate skills development, which are integral parts of a successful transition to digital transformation. These support services help SMEs implement effective digital transformation and ensure sustainable business growth.

In Ukraine, the processes of creating digital centres have begun and work is underway to develop them on the way to transition to EDIH. In practice, in 2020, the Center 4.0 of Igor Sikorsky KPI was registered on the Smart Specialization Platform, which allowed it to receive the official status of Center 4.0 KPI DIH and, with the support of the Association of Industrial Automation Enterprises of Ukraine (APPAU), to participate in the BOWI project and win by becoming one of the members of this community. Today, the participants of the community are active members: the Netherlands, Germany, Finland, Norway, Latvia, Lithuania, Poland, the Czech Republic, Bulgaria and Romania, to which new members have joined as a result of the "pioneer" phase: Ukraine, Slovakia, Hungary, Croatia and Serbia. This means that it is a regional fellowship with a defined mission and goals.

The specialisations of the Centre 4.0 KPI DIH, according to the model of the European Digital Hubs, are cyber-physical systems, the Internet of Things, big data and cloud computing, robotics, additive technologies, system modelling, laser technologies, digital twins and artificial intelligence. The actual implementation of the innovative initiative in Ukraine has the following results More than 50 applications were submitted to the internal competition held in cooperation with the experts of the Centre 4.0 KPI DIH. 14 scientific and pedagogical employees of Igor Sikorsky KPI, leading researchers in DIH specialisations. As a result of this work, 35 project proposals were submitted for the second phase of the BOWI competition, which is the largest number compared to the proposals submitted by other digital centres (figure 6).

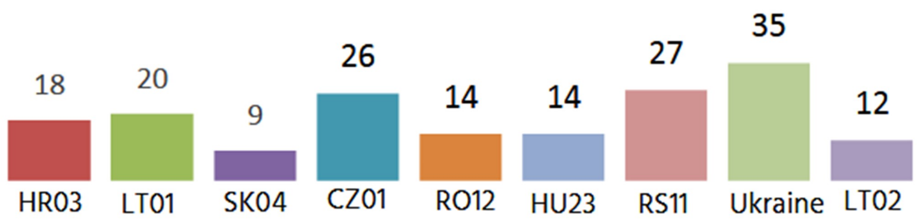

Figure 6: The number of submitted applications for the second phase of the BOWI competition: HR03 – Adriatique, Croatia; LTO1 – Capital Region, Lithuania; SKO4 – Eastern Slovakia, Slovakia, CZ01 – Prague, Czech Republic; RO12 – Center, Romania; HU23 – Southern, Hungary; RS11 – Belgrade, Serbia; Ukraine – Center 4.0 KPI DIH, Igor Sikorsky KPI; LTO2 – Central and Western region, Lithuania.

Applications from SMEs submitted to the competition covered all specialisations of the Center 4.0 KPI DIH. Four SMEs won the competition and received grants for the implementation of digital transformation projects. This example shows an effective combination of science, education and business, which makes it possible to achieve effects for all participants: companies implement technologies that increase their competitiveness on the international market; scientists receive feedback from practitioners when implementing ideas and developments and also have the opportunity to implement applied developments based on basic research; employees of companies increase their level of knowledge and professional skills to ensure the possibility of applying innovative technologies and maintaining equipment, which also brings positive effects for the company and society; state institutions, the government – creation of additional jobs, increase in tax revenues, etc.

In 2022 Ukraine joined the Digital Europe programme [51], and in late 2023 and early 2024 a competition was announced for Ukraine to create and support European Digital Innovation Hubs. Center 4.0 KPI DIH became part of the consortium EDIH "Kyiv Hitech". The basis of the consortium consists of 2 Kyiv DIHs – Center 4.0 KPI DIH and "Virtual Center of Digital Innovations" of Kyiv Academic University NOSC-UA DIH. The consortium includes Ukrainian branches of Siemens and Festo brands, IT-Enterprise, Ukrainian digital product developers, 482.Solutions, Waste Ukraine Analytics, ecosystem partners – Ukrainian cluster alliance, APPAU, innovation holding "Sikorsky Challenge", Digital Transformation Institute and Innovation Development Center , Kyiv Regional Military Administration and public organization "Research Institute of Post-War Rehabilitation and Prosthetics".

According to the results of the competition, the “Kyiv Hitech” consortium did not receive funding from the European Commission, but received the Seal of Excellence, which is considered an EDIH certificate for possible support by national structures, other donors and participation in subsequent European Commission competitions for EDIHs. This composition of the consortium will allow EDIH to cover the maximum needs of SMEs in the Kyiv region, taking into account the smart specialization for this territory. As part of the consortium, Center 4.0 KPI DIH [52] has formed a portfolio of services that it is ready to provide to SMEs: development and testing of prototypes, fundraising for European grants in the field of Industry 4.0, incubation – acceleration of start-ups and innovative developments in the field of I4.0, training programs in areas of specialisation. We believe that the experience of Centre 4.0 KPI DIH can be scaled across Ukraine, which will increase the level of innovative development of the country and its competitiveness.

5. Conclusions

The results of the study indicate a high level of development and spread of digital technologies in Ukraine and the world. According to experts, this trend will continue in the future. Ukraine has significant potential for further development in this direction. The benefits of digital technologies at this stage of development are felt at all levels, including intergovernmental organisations, national governments, innovative companies, service providers and end users. In particular, the main advantages of using these technologies in business are the possibility of forecasting sales markets and creating competitive advantages, automation of business processes, monitoring the condition of equipment and timely implementation of preventive measures, minimising costs, improving the quality of products (services), providing remote service and support in any country in the world, etc. As a result, governments and citizens of countries receive additional benefits.

At the same time, significant risks and threats associated with the use of digital technologies should be taken into account. The main risks include the potential increase in unemployment due to the replacement of human labour by machines in the use of the latest technologies, growing threats to cybersecurity, confidentiality and privacy, the reliability of solutions proposed by AI, loss of control, etc. From the point of view of innovative companies and suppliers, we note the existence of problems such as the quality of data for training neural networks; the quality of human resources; the availability of financial resources and the appropriate material and technical base; the lack of marketing skills to promote innovative solutions on the market. These issues are particularly relevant for SMEs.

In order to increase the effectiveness of the implementation of digital transformations, it is proposed to form an innovative ecosystem that includes the interests of all participants and stakeholders. The basis of this ecosystem should be the interrelationships between science, education and business. As an example, the implementation of the Digital Innovation Hub model is proposed. The experience with the implementation of this approach at the KPI named after Igor Sikorsky showed very positive results from the cooperation of scientists, educators, SMEs and international partners. The proposed model of economic use allows to make a preliminary assessment of the cost of economic resources and time and to minimise risks at the stage of project development and implementation. The advantage of the proposed approach is that it takes into account the individual needs of clients and users at the stage of task definition and comparative evaluation of available alternatives. We believe that a systematic approach to building science-education-business relationships based on digital technologies will contribute to increasing the level of human potential and solving economic and socio-economic problems. In order to solve these problems and increase the competitiveness of the domestic digital technologies sector, it is appropriate to pay more attention to local digital innovation centres. At the same time, it will contribute to the formation of a national innovation ecosystem with the participation of all potential stakeholders.

References

[1] O. Pupena, L. Sobolevska, Analiz opytuvannia APPAU shchodo pidvyshchennia kvalifikatsii spetsialistiv z promyslovoi avtomatyzatsii [Analysis of the APAU survey regarding professional development of industrial automation specialists], 2024. URL: https://appau.org.ua/news/analysis-survey-training-industrial-automation/.

[2] M. Bulgheroni, V. Tageo, G. Badone, A. Corsello, How the Digital Transformation can put humans at the centre of robotics and automation: Collaboration between humans and machines for better quality products and services, European Economic and Social Committee, 2021. URL: https://www.eesc.europa.eu/sites/default/files/files/qe-01-20-716-en-n.pdf.

[3] A. M. Al-Abdullatif, A. A. Gameil, Exploring Students' Knowledge and Practice of Digital Citizenship in Higher Education, International Journal of Emerging Technologies in Learning 15 (2020) 122–142. doi:10.3991/ijet.v15i19.15611.

[4] A. Bhutoria, Personalized education and Artificial Intelligence in the United States, China, and India: A systematic review using a Human-In-The-Loop model, Computers and Education: Artificial Intelligence 3 (2022) 100068. doi:10.1016/j.caeai.2022.100068.

[5] T. Pencarelli, The digital revolution in the travel and tourism industry, Information Technology & Tourism 22 (2020) 455–476. doi:10.1007/s40558-019-00160-3.

[6] A. Balula, G. Moreira, A. Moreira, E. Kastenholz, C. Eusébio, Z. Breda, Digital transformation in tourism education, in: ToSEE – Tourism in Southern and Eastern Europe, volume 5, 2019, pp. 61–72. URL: https://www.researchgate.net/publication/335804249. doi:10.20867/tosee.05.45.

[7] P. Dhar, T. Rocks, R. M. Samarasinghe, G. Stephenson, C. Smith, Augmented reality in medical education: students' experiences and learning outcomes, Medical Education Online 26 (2021). doi:10.1080/10872981.2021.1953953.

[8] K. K. O'Brien, F. Ibáñez-Carrasco, K. Birtwell, G. Donald, D. A. Brown, A. D. Eaton, B. Kasadha, E. Stanmore, N. St. Clair-Sullivan, L. Townsend, J. H. Vera, P. Solomon, Research priorities in HIV, aging and rehabilitation: building on a framework with the Canada-International HIV and Rehabilitation Research Collaborative, AIDS Research and Therapy 20 (2023) 86. doi:10.1186/s12981-023-00582-4.

[9] G. D. Patrón, L. Ricardez-Sandoval, An integrated real-time optimization, control, and estimation scheme for post-combustion CO_2 capture, Applied Energy 308 (2022) 118302. doi:10.1016/j.apenergy.2021.118302.

[10] W. Liu, B. Li, Z. Ji, Internet of Things and Digital Twin Technology-Based Management System of Medical Equipment, Global Clinical Engineering Journal 6 (2023) 46–53. doi:10.31354/globalce.v6i1.164.

[11] E. Mogaji, V. Jain, How generative AI is (will) change consumer behaviour: Postulating the potential impact and implications for research, practice, and policy, Journal of Consumer Behaviour (2024). doi:10.1002/cb.2345.

[12] N. Y. Skorobogatova, Innovative technologies for organizing a balanced development of the business ecosystem (in the example of agriculture in Ukraine), IOP Conference Series: Earth and Environmental Science 1254 (2023) 012105. doi:10.1088/1755-1315/1254/1/012105.

[13] A. Lewandowska, J. Berniak-Woźny, N. Ahmad, Competitiveness and innovation of small and medium enterprises under Industry 4.0 and 5.0 challenges: A comprehensive bibliometric analysis, Equilibrium. Quarterly Journal of Economics and Economic Policy 18 (2023) 1045–1074. doi:10.24136/eq.2023.033.

[14] European innovation scoreboard, 2024. URL: https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en.

[15] C. Alcaraz, J. Lopez, Digital Twin: A Comprehensive Survey of Security Threats, IEEE Communications Surveys & Tutorials 24 (2023) 1475–1503. doi:10.1109/COMST.2022.3171465.

[16] H. M. Alzoubi, T. M. Ghazal, M. K. Hasan, A. Alketbi, R. Kamran, N. A. Al-Dmour, S. Islam, Cyber Security Threats on Digital Banking, in: 2022 1st International Conference on AI in Cybersecurity (ICAIC), 2022, pp. 1–4. doi:10.1109/ICAIC53980.2022.9896966.

[17] K. Demestichas, N. Peppes, T. Alexakis, Survey on Security Threats in Agricultural IoT and Smart Farming, Sensors 20 (2020) 6458. doi:10.3390/s20226458.

[18] S. Quach, P. Thaichon, K. Martin, S. Weave, R. Palmatie, Digital technologies: tensions in privacy and data, Journal of the Academy of Marketing Science Article 50 (2022) 1299–1323. doi:10.1007/s11747-022-00845-y.

[19] M. L. Miller, C. Vaccari, Digital Threats to Democracy: Comparative Lessons and Possible Remedies, The International Journal of Press/Politics 25 (2020) 333–356. doi:10.1177/1940161220922323.

[20] A. Frandell, M. Feeney, Cybersecurity Threats in Local Government: A Sociotechnical Perspective, The American Review of Public Administration 52 (2022) 558–572. doi:10.1177/02750740221125432.

[21] N. Saxena, E. Hayes, E. Bertino, P. Ojo, K.-K. R. Choo, P. Burnap, Impact and Key Challenges of Insider Threats on Organizations and Critical Businesses, Electronics 9 (2020) 1460. doi:10.3390/electronics9091460.

[22] A. Bécue, I. Praça, J. Gama, Artificial intelligence, cyber-threats and Industry 4.0: challenges and opportunities, Artificial Intelligence Review 54 (2021) 3849–3886. doi:10.1007/s10462-020-09942-2.

[23] J. Wang, Y. Liu, P. Li, Z. Lin, S. Sindakis, S. Aggarwal, Overview of Data Quality: Examining the Dimensions, Antecedents, and Impacts of Data Quality, Journal of the Knowledge Economy 15 (2024) 1159–1178. doi:10.1007/s13132-022-01096-6.

[24] N. Baur, P. Graeff, L. Braunisch, M. Schweia, The Quality of Big Data. Development, Problems, and Possibilities of Use of Process-Generated Data in the Digital Age, Historical Social Research 45 (2020) 209–243. doi:10.12759/hsr.45.2020.3.209-243.

[25] T. A. Vakaliuk, D. S. Antoniuk, The use of digital technology in general secondary education in Ukraine: current state and future prospects, in: S. Papadakis (Ed.), Proceedings of the VIII International Workshop on Professional Retraining and Life-Long Learning using ICT: Person-oriented Approach (3L-Person 2023), Virtual Event, Kryvyi Rih, Ukraine, October 25, 2023, volume 3535 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2023, pp. 17–31. URL: https://ceur-ws.org/Vol-3535/paper01.pdf.

[26] V. Tkachuk, Y. V. Yechkalo, S. Semerikov, M. Kislova, V. Khotskina, Exploring Student Uses of Mobile Technologies in University Classrooms: Audience Response Systems and Development of Multimedia, in: O. Sokolov, G. Zholtkevych, V. Yakovyna, Y. Tarasich, V. Kharchenko, V. Kobets, O. Burov, S. Semerikov, H. Kravtsov (Eds.), Proceedings of the 16th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kharkiv, Ukraine, October 06-10, 2020, volume 2732 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2020, pp. 1217–1232. URL: https://ceur-ws.org/Vol-2732/20201217.pdf.

[27] S. Lytvynova, N. Vodopian, O. Sysoeva, Artificial Intelligence in Secondary Education: An Innovative Teacher's Tool to Ensure Individualised Learning for Students, in: Ł. Tomczyk (Ed.), New Media Pedagogy: Research Trends, Methodological Challenges, and Successful Implementations, volume 2130 of *Communications in Computer and Information Science*, Springer Nature Switzerland, Cham, 2024, pp. 393–412. doi:10.1007/978-3-031-63235-8_26.

[28] T. A. Vakaliuk, V. V. Kontsedailo, D. S. Antoniuk, O. V. Korotun, I. S. Mintii, A. V. Pikilnyak, Using game simulator Software Inc in the Software Engineering education, in: A. E. Kiv, M. P. Shyshkina (Eds.), Proceedings of the 2nd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, March 22, 2019, volume 2547 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2019, pp. 66–80. URL: https://ceur-ws.org/Vol-2547/paper05.pdf.

[29] T. H. Kolomoiets, D. A. Kassim, Using the Augmented Reality to Teach of Global Reading of Preschoolers with Autism Spectrum Disorders, in: A. E. Kiv, V. N. Soloviev (Eds.), Proceedings of the 1st International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, October 2, 2018, volume 2257 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2018, pp. 237–246. URL: https://ceur-ws.org/Vol-2257/paper24.pdf.

[30] M. Popel, S. V. Shokalyuk, M. Shyshkina, The Learning Technique of the SageMathCloud Use for

Students Collaboration Support, in: V. Ermolayev, N. Bassiliades, H. Fill, V. Yakovyna, H. C. Mayr, V. S. Kharchenko, V. S. Peschanenko, M. Shyshkina, M. S. Nikitchenko, A. Spivakovsky (Eds.), Proceedings of the 13th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer, ICTERI 2017, Kyiv, Ukraine, May 15-18, 2017, volume 1844 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2017, pp. 327–339. URL: https://ceur-ws.org/Vol-1844/10000327.pdf.

[31] P. Nechypurenko, T. Selivanova, M. Chernova, Using the Cloud-Oriented Virtual Chemical Laboratory VLab in Teaching the Solution of Experimental Problems in Chemistry of 9th Grade Students, in: V. Ermolayev, F. Mallet, V. Yakovyna, V. S. Kharchenko, V. Kobets, A. Kornilowicz, H. Kravtsov, M. S. Nikitchenko, S. Semerikov, A. Spivakovsky (Eds.), Proceedings of the 15th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kherson, Ukraine, June 12-15, 2019, volume 2393 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2019, pp. 968–983. URL: https://ceur-ws.org/Vol-2393/paper_329.pdf.

[32] D. Y. Bobyliev, E. V. Vihrova, Problems and prospects of distance learning in teaching fundamental subjects to future Mathematics teachers, Journal of Physics: Conference Series 1840 (2021) 012002. doi:10.1088/1742-6596/1840/1/012002.

[33] N. O. Zinonos, E. V. Vihrova, A. V. Pikilnyak, Prospects of Using the Augmented Reality for Training Foreign Students at the Preparatory Departments of Universities in Ukraine, in: A. E. Kiv, V. N. Soloviev (Eds.), Proceedings of the 1st International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, October 2, 2018, volume 2257 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2018, pp. 87–92. URL: https://ceur-ws.org/Vol-2257/paper10.pdf.

[34] O. O. Lavrentieva, I. O. Arkhypov, O. P. Krupski, D. O. Velykodnyi, S. V. Filatov, Methodology of using mobile apps with augmented reality in students' vocational preparation process for transport industry, in: O. Y. Burov, A. E. Kiv (Eds.), Proceedings of the 3rd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, May 13, 2020, volume 2731 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2020, pp. 143–162. URL: https://ceur-ws.org/Vol-2731/paper07.pdf.

[35] K. Vlasenko, S. Volkov, I. Sitak, I. Lovianova, D. Bobyliev, Usability analysis of on-line educational courses on the platform "Higher school mathematics teacher", E3S Web of Conferences 166 (2020) 10012. doi:10.1051/e3sconf/202016610012.

[36] Association of Industrial Automation of Ukraine, 2024. URL: https://appau.org.ua/.

[37] EIS interactive tool 2024 | Research and Innovation: Indicator profile, 2024. URL: https://projects.research-and-innovation.ec.europa.eu/en/statistics/performance-indicators/european-innovation-scoreboard/eis-2024#/eis/indicators/1.3?country_scope=all.

[38] Ministry of Digital Transformation of Ukraine, Index of digital transformation of regions of Ukraine, 2024. URL: https://thedigital.gov.ua/news/rezultati-tsifrovoi-transformatsii-v-regionakh-ukraini-za-2023-rik.

[39] Information technologies of Ukraine, 2024. URL: https://catalog.youcontrol.market/informatsiini-tekhnolohii.

[40] Ukrainian Cluster Alliance — Association of Ukrainian organizations for the development of the cluster movement and economic growth, 2024. URL: https://www.clusters.org.ua/.

[41] F. Tennant, Shaping the future: value creation in digital infrastructure, 2022. URL: https://www.financierworldwide.com/shaping-the-future-value-creation-in-digital-infrastructure.

[42] A. Krupianyk, Digital Economy of Ukraine: Key Development Factors, 2023. URL: https://voxukraine.org/en/digital-economy-of-ukraine-key-development-factors.

[43] Grammarly, 2024. URL: https://www.grammarly.com/.

[44] Unlock your GTM's complete story with SalesAI, 2024. URL: https://www.people.ai/.

[45] I. Malashenko, Blitz on the development of AI in Ukraine. We speak with Valdis Gerasymyak, Lead Deep Learning Engineer at Ajax, 2023. URL: https://dou.ua/lenta/interviews/ai-in-ukraine/.

[46] O. Litskevich, How to sell technology. Interview with SMO Ajax Systems Valentyn Hrytsenko, 2024. URL: https://tech.liga.net/ua/technology/interview/yak-prodavaty-tekhnolohii-ta-obiity-konkurentiv-interviu-z-smo-ajax-valentynom-hrytsenkom.

[47] Fozzy Group has developed and is testing its own artificial intelligence - how it works, 2023. URL: https://www.ucsc.org.ua/fozzy-group-rozrobyla-i-testuye-vlasnyj-shtuchnyj-intelekt-yak-vin-praczyuye/.
[48] Ukrainian associations have joined the network of European digital innovation hubs, 2024. URL: https://thedigital.gov.ua/news/ukrainski-obednannya-uviyshli-do-merezhi-evropeyskikh-tsifrovikh-innovatsiynikh-khabiv.
[49] Digital Transformation in Industry, White Paper, An Industrial Internet Consortium, Chicago, 2020. URL: https://www.iiconsortium.org/pdf/Digital_Transformation_in_Industry_Whitepaper_2020-07-23.pdf.
[50] P. Schalkwyk, Lean Digital Twin: Part 1, 2020. URL: https://xmpro.com/lean-digital-twin-part-1/.
[51] EU program Digital Europe (2021-2027), 2021. URL: https://business.diia.gov.ua/en/digital-europe-programme.
[52] Centre 4.0 KPI DIH, 2024. URL: https://dih.kpi.ua/.