# Analysis and New Approaches to Solving the Problems of Integration of E-Science and E-Education Based on the Challenges of Industry 4.0

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***Abstract*—Industry 4.0 relies on the introduction of digital technologies for collecting, processing, and analyzing data, providing useful information for digital decisions. This work studies the problems of integration of e-science and e-education based on Industry 4.0 solutions. It analyzes the current state of affairs, identifies the problems and provides conceptual directions for their solution, thereby creating conditions for developing new, more effective, and innovative methods of management, research, and training. In general, the proposed conceptual approach to the integration of e-education and e-science involves combining technologies, methods and approaches taking into account social, economic, and cultural aspects of the issue.**

***Keywords*—*e-science, e-education, integration of science and education, Industry 4.0, Science 4.0, Education 4.0***

## I. Introduction

Being the latest trend in the industrial revolution, Industry 4.0 is a concept of digital economy that covers all areas of social life. E-science and e-education play an important role in improving the quality of science and education the main components boosting the development of the information society and are successfully developing in parallel. However, these two areas often function independently, often ignoring the opportunities and requirements of Industry 4.0. The integration of e-science and e-education based on Industry 4.0 solutions can solve this problem and create conditions for the development of new, more effective and innovative methods of research and teaching. Therefore, the study of problems related to the integration of e-science and e-education based on Industry 4.0 solutions is a hot topic of scientific and practical discussions. The main objectives of the integration of e-science and e-education include the joint use of scientific and educational potential of organizations with mutual interests, particularly in training, advanced training and retraining of personnel, as well as joint scientific research, implementation research, improvement management processes, etc. Thus, the advent of Industry 4.0, opens up prospects for the development and integration of e-science and e-education. The ongoing transformation of e-science and e-education based on such advanced technologies as the Internet of Things (IoT), Cyber-Physical Systems (CPS), Artificial Intelligence (AI), Big Data Analytics, etc. creates ample opportunities for restructuring and integration of science and education as corporate environments in the format of Science 4.0 and Education 4.0. Accordingly, as opposed to conventional science and education systems, Science 4.0 and Education 4.0 form an evolutionary corporate environment that combines information from the real and virtual worlds, taking into account the technological tools of the new digital age.

The purpose of this article is to study the main trends in the integration of e-science and e-education, as well as to consider them in the context of their relationship with Industry 4.0.

## II. Problems of Integrating E-Science, E-Education and Industry 4.

The challenges put forward by the 4th industrial revolution (Industry 4.0) initiated, a new stage for building the information society throughout the world. This includes intelligent automation systems, connecting physical and digital worlds through IoT and CPS. According to Action Line C7 (ICT applications: benefits in all aspects of life) of the World Summit on the Information Society (WSIS, 2003), e-science and e-education platforms have collectively initiated the transition to the widespread use of ICTs in science and education. Ongoing activities in this area have accelerated the successful implementation of e-science and e-education playing an instrumental role in boosting the sustainable development, as well as increasing transparency and accountability [1]. So, in addition to informatization, these structures are consistently working on the formation of a single information space suitable for the use of each of them, the development of information resources, and infrastructures. The purpose of the ongoing work is to ensure the collaboration of scientific and educational institutions, as well as researchers and educators, in the virtual space and to ensure their access to appropriate information and communication infrastructure and broadband Internet to scientific, technical and educational information and computing resources. At the same time, e-science and e-education can be considered separately as complex systems with technical and technological components, consisting of infrastructure subsystems for generating, collecting, storing, processing, searching, analyzing, transmitting, presenting data, etc.

Industry 4.0 features a high level of complexity and provides full network integration of products and production processes. This concept represents a new industrial phase of production systems through the application of advanced technologies that add value to the entire product life cycle. The chart below (Fig. 1) shows the top 10 Industry 4.0 trends and innovations in 2023 [2].

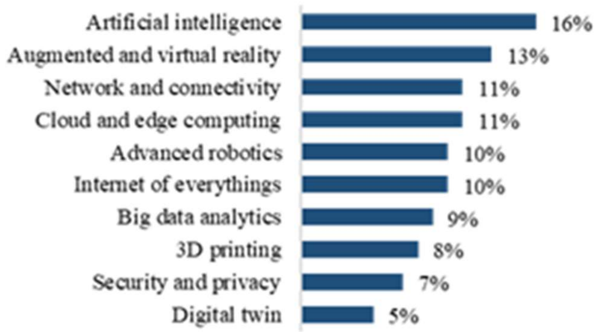


Fig. 1. Top 10 Industry 4.0 trends

The integration of scientific and educational environment based on this concept can be implemented by combining Science 4.0 [3] and Education 4.0 [4] into a single corporate environment. Overall, the approach outlined in [1] provides a solid foundation for adopting e-science as the technical and technological basis for Science 4.0, and e-education, for Education 4.0. Thus, Science 4.0 and Education 4.0 can be seen as an evolution of e-science and e-education. Therefore, by regarding them as a single system, we can get a new platform for integrating science and education.

The above approach is largely based on the transformation models being developed by modern high-tech companies. During this transformation, the company is transformed into a constantly evolving organization which can easily and continuously adapt to changing conditions through the use of advanced Industry 4.0 technologies, continuous professional development of personnel, and effective decision-making based on complete, reliable, and quickly available data. So, the conceptual model of this approach takes into account the solutions provided by the Industry 4.0 technologies, such as smart laboratories, libraries, universities, buildings, and cities, digital twins, etc. The conceptual issues of implementing this approach include the following:

- Science and education are perceived as a single corporate environment;
- Its physical infrastructure includes telecommunications networks, data centers, buildings, research and teaching facilities, etc.

Along with the advantages, this integration process also poses a number of technological and technical problems, including the necessity to revise conventional approaches, personnel qualification, inequality of access, data security and privacy.

## III. Related Studies

This study is based on fundamental and applied works on the transformation of forms and models of interaction between scientific and educational institutions challenged by Industry 4.0. Authors reviewed and analyzed the relevant literature and articles from academic databases to evaluate the state of research on the use of Industry 4.0 technologies in e-science and e-education and prospects in this direction. To show how relevant the problem is, we will consider only some of them as examples, given the limitations of this article.

The available scientific literature actively explores the possibility of using Industry 4.0 technologies that support data management and processing for the provision of various types of science and education services. It provides numerous examples of cutting-edge research in informatics and complex industrial systems, covering topics such as health informatics, bioinformatics, brain informatics, genomics and proteomics, data and network security [5].

[6] shows, the contemporary trends in educational technologies for 2023, which make the learning process more adaptable, accessible, and interactive for both students and teachers.

[3] is the analysis of science in the new Science 4.0 format with the broad involvement of the Industry 4.0 technology platform. It explores the problems related to the development of this concept. Science 4.0 is considered a set of interconnected intellectual subsystems interacting with each other and the external environment through material, technical and information means to achieve the set goals. Such a conceptual approach can be adopted for the educational environment, gradually evolving into Education 4.0.

The purpose of the systematic literature review conducted in Scopus [7] is to determine the scope of Industry 4.0 technologies are used in education. The results showed that augmented reality, simulation, IoT and virtual reality are used more in higher education. Such applications are used collectively to increase student immersion engagement, and interpersonal interaction, reduce costs and risks, simulate real work scenarios, expand study possibilities, without limited time and space, develop social skills and learn technology.

An important task in the integration of e-science and e-education is assigned to the specialized Internet service provider National Research and Education Network (NREN). Based on this network, [8] proposes an e-learning reference model and related templates that take into account connectivity, secure access, collaboration, and interaction between e-learning platforms.

[9] presents peer-reviewed materials on smart universities. It explores, various issues of smart universities as a new and rapidly developing field that creatively integrates innovative concepts; intelligent software and hardware systems; smart classes with modern technologies and technical platforms; smart teaching based on modern teaching and learning strategies; intellectual learning and academic analytics.

Data science and AI applications are important and promising areas in science and education systems. For example, AI-based applications are being used at different levels of education. [10] provides an analysis and synthesis of processes, practices, applications, and tools of AI intelligence in education. In [11], new AI learning concepts have been developed to improve AI literacy.

Self-driving labs, combining fully-automated experiments with AI to decide on the next set of experiments, may become a new paradigm of scientific research [12].

CPS applications, which are the main trend of Industry 4.0, are widely used in both management and research processes. The study of modern trends in their integration into the environment of e-science is relevant [13]. In this paper, the e-science environment is considered in the context of a smart city. It presents the possibilities of using cloud, fog, dew computing, and blockchain technologies, as well as a technological solution for decentralized scientific data processing.

The large volumes of data generated in science and education systems provide unique opportunities for applying big data analytics and learning, understanding, and modeling processes. For example, [14] proposes a set of unified definitions and an integrated framework for data analysis in higher education.

The use of advanced Industry 4.0 solutions for the integration of scientific and education systems, along with financial, regulatory, technical, and technological problems, necessitates ensuring complex security. [15] studies the security issues in the context of Science 4.0, thereby developing priority areas for ensuring complex security and mechanisms for their solution.

Thus, the reviewed literature confirms that Industry 4.0 has excellent potential for the development and integration of science and education.

## IV. Methodology

The research methodology includes the synthesis of a conceptual model based on the study, comparative analysis, and generalization of works on the application of the most critical technologies of Industry 4.0 to the integration of e-science and e-education. To do this, a search was carried out in scientific databases. In addition, a comparative historical analysis of large amount of related data was carried out to determine the relationships and indicators of e-science and e-education.

Finally, its summaries the meaning of the data and chooses e-science and e-education as the technology base. As a result, Science 4.0 and Education 4.0 are combined into a single format, thereby regarded as a corporate environment for the restructuring and integration of e-science and e-education. The result of the transformation is a system presented as a set of interconnected intellectual subsystems that interact with each other and with the external environment through the using material, technical and information means to achieve the goals. It is also proposed to use the concept of a smart city to manage scientific and educational infrastructure, personnel, unique equipment, etc., to use the potential of research groups more effectively to improve the concept.

## V. Conceptual Issues of Integration of E-Science And E-Education on The Industry 4.0 Platform

The integration of e-science and e-education on the Industry 4.0 platform can be approached from a conceptual point of view, considering the areas where they can be combined to create mutually beneficial relationships. When implementing Industry 4.0, there are six key design principles such as interoperability, information transparency, technical support, real-time data collection and processing, modularity, and distributed solution. Based on these principles, the integration of e-science and e-education on the Industry 4.0 platform covers a wide range of different areas of activity and manifests itself in a wide variety of forms, the main ones being the following:

- integration and development of network infrastructures under the single name NREN to provide advanced ICT services to the research and educational community;
- integration, development and management of information infrastructures and resources of data centers;
- sharing of existing e-resources, e-libraries [16], and the development of multipurpose new smart resources;
- automation of sharing processes with the widespread use of IoT, CPS, AI, Big data analytics and other advanced technologies, new generation equipment and devices and the development of new smart systems for various purposes;
- organization and expansion of joint activities, participation of scientists in the education process, and the inclusion of teachers and students in the scientific research;
- high-quality support for the scientific and educational process and management;
- ensuring integrated security (cybersecurity and cyber resilience);
- personnel management and training of a new type of personnel focused on the digital reality of the challenges of Industry 4.0 (smart scientist, smart teacher, smart teacher, smart student).

E-science and e-education network platforms play a fundamental role in this process. With the integration of these existing networks and computing e-infrastructures, NREN is able to create an efficient connection between structures, provide a variety of services to users, and at the same time integrate with international scientific and educational networks.

Remarkably, sensors are becoming one of the main sources of data for the integration process. There is an exponential growth in the number of IoT devices equipped with them [17]. The spread of IoT applications and the critical growth of requirements for efficiency and productivity of their tasks increasingly require data processing being closer to the location of applications using them. These problems are solved by moving analytics to the edge level of fog and dew computing [18, 19]. According to the generally accepted decentralized information processing model, Science 4.0 proposes to use a universal three-tier architecture - Edge, Fog, and Cloud.

Applications used for the integration of scientific and educational environment can be grouped by data sources as follows:

- *Primary data sources* at the physical object level. These include sensors, IoT devices, special equipment, security systems, etc. These sources, especially IoT, provide a large amount of data continuously generated at high speed in real time. Meanwhile, the growing number of mobile devices connected to 5G networks increases the volume of collected data. The application of mobile Edge-AI methods to solve this type of data problem, especially in 5G networks, allows for quickly and comprehensively analyzing data to make better decisions [20].
- *Virtual data sources*. These include e-libraries, scientific publications, multifunctional information systems and electronic resources. As the key components of information support for science and education, this group represents a large number of sources with valuable knowledge on the management of science and education. Effective results can be

achieved through the use of automated agents based on Edge-AI methods in decision making.

Thus, data becomes the leading factor in the integrating process. For efficient storage and management of collected Big data, depending on the frequency of the use, a data lake strategy can be adopted [21]. This organization of the data in its original form gives scientific and educational organizations, as well as researchers, the flexibility for analysis.

It is also necessary to improve the infrastructure to support the reuse of scientific and educational data. This requires data to be found, accessible, interoperable and reusable (FAIR) in the long term. [22] discusses the development of sufficient and measurable sets of principles, called FAIR Data Principles. They are intended to serve as a guide for those who want to increase the reusability of data storage facilities.

Digital twins have increased the value of data. They reflect a two-way dynamic display of the studied processes and virtual models. In particular, this is the virtualization of physical objects [23]. The physical process is evaluated, analyzed, predicted and optimized by virtual means. In this way, the digital twin facilitates efficient communication between the various stages of the study, enabling iterative optimization.

This conceptual approach increases the role of protection of infrastructures, equipment, systems and other resources, their maintenance, information security and cybersecurity in scientific and education systems. [24] presents an intelligent service framework and discusses its key components. This an AI and IoT service platform that combines real-time data collection, transmission, and storage using wireless sensors and big data technologies, continuous learning, and the deployment of machine learning models.

The presented conceptual approach opens up wide opportunities for the development and integration of open science and open education initiatives. [25] explores open science in relation to educational practices and resources, and provides recommendations for improving the support and infrastructure of open practices.

This integration process, underlines the significance of the Citizen Science (CS) thanks to its wide range of opportunities. As a new area of e-science, CS plays an increasingly important role in the development of education and the expansion of learning opportunities as a means of voluntary cooperation of citizens in scientific research. The introduction of Industry 4.0 technologies, has accelerated this process. For example, the European CS platform [26] makes CS projects and data more accessible also serves being a collaborative space and a testing ground for integrating science and education.

Eventually, the ongoing research and practical achievements in the above areas will:

- accelerate of the integration of science and education, transforming them to a single social institution, and consolidating their mutual development;
- ensure the efficient use of facilities and resources, including infrastructure, and e-resources;
- increasing the effectiveness of science, education, and management;
- expand the introduction of the results of scientific research in education, thereby developing high-level human capital;
- improve the quality and effective management of science and higher education, as well as preschool and general education, etc.

The introduction of advanced technologies under Industry 4.0 will ensure higher productivity, greater flexibility, better control and optimization of processes, sustainable development and other benefits to these institutions.

## VI. Conclusion

The large-scale use of information technologies in industrial production, as part of Industry 4.0 has a decisive impact on all spheres of human activity: economy, public administration, and social life. It also has a direct impact on both processes and management of science and education opening up wide opportunities for interaction between the two. Authors have collected and analyzed articles related to the introduction of key Industry 4.0 technologies, such as the IoT, CPS, AI, Big data and other intelligent scientific and education solutions. Conceptual directions for the integration of science and education based on the platform of e-science and e-education have been developed in accordance with the requirements of Industry 4.0. An analysis of research work on the introduction of key Industry 4.0 technologies into science and education confirms that new prospects are opening up for the development of these areas. Thus, the integration of e-science and e-education based on the digital technologies of Industry 4.0 transforms in the organization management processes and alters relations through the development and dissemination of technological innovations. As a result, the participants in this environment, property, equipment, processes, and resources are combined in a new way, with data being collected and analyzed in real-time. This also ensures effective management and development of science and education, training of high-quality personnel, and other benefits.

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