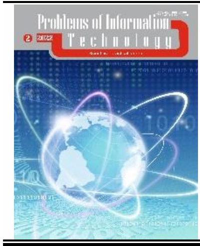

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THE IMPACT OF INDUSTRY 4.0 ON THE FORMATION OF SCIENCE 4.0

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ABSTRACT

Technological innovations at the forefront of industrial revolutions are applied not only in industry but also create a need for research and applications, as a result of which they are mastered and penetrate other areas of human activity. In this regard, the latest advances in information technology in the field of data generation, storage, transmission and processing during the 4th industrial revolution have led to the transformation of traditional scientific activity and the rapid development of the concept of "data-based science". The article analyzes the main development stages in the scientific environment, the organization of scientific activities with the widespread use of Industry 4.0 solutions, and its organic connection with the concept of Science 4.0. The essence of Science 4.0 is revealed through the review of studies in the field of the Internet of Things, cyber-physical systems, artificial intelligence, cloud computing, big data analytics, and other intelligent solutions. Conceptual issues of the formation of Science 4.0 are developed and relevant proposals are made for its implementation.

1. Introduction

The formation of modern society became possible due to the radical technological advances that took place at various stages of the development of human civilization and had a huge social and cultural significance. For example, the invention of writing created opportunities for the accumulation and dissemination of knowledge. With the invention of printing, information became more accessible to society. This became one of the reasons for the demand for literacy among the population, and, perhaps, also initiated the processes of acceleration in science and technology.

Indeed, over a long historical epoch, science has developed purely empirically. For example, in the Stone Age, based on numerous observations and experiments, bronze and iron tools were created, which created the conditions for the transition of mankind to a completely new stage of development. The Middle Ages are characterized by the emergence of theoretical models and generalizations in the form of mathematical equations.

Obviously, in the second half of the 18th century in some countries of Western Europe and North America there were processes of accelerating industrial production, later called the first industrial revolution. In parallel with these processes, there is an explosive growth of scientific discoveries and inventions. The continuous development of science and production also occurs during the periods of the second, third and fourth industrial revolutions.

The fourth industrial revolution dates back to 2011 when the concept of "Industry 4.0" was proclaimed at the initiative of the German federal government with the participation of universities and private companies (Kagermann et al., 2013; Lee et al., 2015). Its main task was to develop and implement innovative information technologies in production systems to improve the efficiency and competitiveness of the national industry. Similar industrial modernization programs exist in other countries. For example, Factories of the future in the EU (Jardim-Goncalves et al., 2017).

Industry 4.0 characterizes by a high level of sophistication and full networked integration of products and manufacturing processes. It's based on advanced manufacturing or the concept of intelligent manufacturing, that is, on an adaptable system in which flexible lines automatically adjust production processes for different products and changing conditions. This concept represents a new industrial production phase by integrating new and converged technologies that add value to the entire product lifecycle. It allows for increased quality, productivity, and flexibility and can also help produce customized products on a large scale and sustainable with better resource consumption. In parallel with industry, information and communication technology (ICT) has also contributed to the emergence of new trends in the scientific community.

It became possible to share expensive scientific equipment, supercomputers, distributed data storage, unlimited access to information resources, etc. At the same time, the Internet of Things (IoT), cyber-physical systems (CPS), artificial intelligence (AI), cloud computing, big data, as well as other intelligent solutions began to be applied in scientific laboratories. All this also required organizational work to create an integrated science infrastructure based on smart city solutions.

Thus, following the trends of the fourth industrial revolution, the term Science 4.0 denotes the concept of evolution and formation of the scientific environment under the influence of the ideology of Industry 4.0.

The purpose of this article is to discuss possible directions for the development of Science 4.0 against the background of the general ideas of Industry 4.0.

The article is structured as follows. Section 2 examines the position of science in society, and existing work that can help unravel the essence of Science 4.0. Section 3 is devoted to the rationale for using e-science as a technological platform for Science 4.0, and also analyzes the conceptual issues and ways to solve its formation problem. Finally, section presents conclusion of the study.

2. Related works

The authors set out to study the environment of science and its change under the influence of the technological solutions of Industry 4.0. For this, the method of comparative analysis of published articles in databases by keywords was used.

Radder (2009) note that there is a significant conceptual similarity between the implementation of experimental and technological processes, primarily the implied possibility and necessity of manipulating nature and controlling it. Taken together, these facts justify the claim that the relationship between science and technology should be a central theme in the study of scientific experiments. One obvious way to study the role of technology in science is to focus on the tools and equipment used in experimental practice.

Zezulka et al. (2016) review the cyber-physical and informational foundations of Industry 4.0, as well as the milestones in the design and implementation of Industry 4.0 systems. Proposed RAMI 4.0 (Reference Architecture Model Industry 4.0) model can help in the creation of hardware and software components for scientific research.

It is revealed that in Industry 4.0 an important role is given to AI, which has become an integral part of the implementation of many projects in production, transport, and medicine. Along with this, AI has great prospects in scientific research. In modern science, a situation has arisen when researchers are unable to cope with large amounts of data used in studying the properties of the material world and extracting knowledge.

Note that the first known application of AI to solve scientific reasoning was the Heuristic-DENDRAL program. Another version of it, called Meta-DENDRAL, became the first expert system to form scientific hypotheses. For example, this expert system has proposed some ideas to explain the correlation between specific designs and the mass spectrum (Sparkes et al., 2010).

Banerji et al. (2010) propose to use such a field of AI as machine learning in the morphological classifications of telescope images in the Sloan Digital Sky Survey DR6 astrophysics project. Senior et al. (2020) propose improved protein structure prediction using deep learning potentials.

The topic of Big data and its integration with AI is of great interest to researchers (Fataliyev & Mehdiyev, 2019a). Big data analytics (BDA) develops a methodological analysis of Big data structures, which is often grouped in the following categories: volume, velocity, variety, veracity, and value. When combined with AI, BDA can transform the fields of manufacturing, healthcare, and business intelligence by offering advanced incentives within a predictive context (Shukla et al., 2019). In addition, research related to diagnosing and predicting the health of patients based on AI and big data shows that they have significant potential (Beregi et al., 2018).

For successful decisions in Big data structures, tools, and methods of data visualization are also used. In scenarios that take human perception and cognition limitations into account, a higher level of understanding and interpretation can gain from analyzing and presenting data using AI technologies. Zhong et al. (2017) focus on the extraction of important valuable and critical management information using intelligent AI-based visualization tools.

However, the formation of Science 4.0 is not limited to the potential of AI and BDA to enhance the cognitive abilities of researchers.

Collection and storage of data are significant challenges. Modern scientific research can generate gigabytes or terabytes of data, forcing researchers to find places to store it. A complex drive farm large enough to hold this amount of data will take up most of the space. Cloud computing eliminates the need for hard drives in place, creating more space for experimentation or equipment (Nichols, 2019).

It should be noted that in the scientific method there is a transition from single observations to large-scale data processing. At the same time, the application of Industry 4.0 technologies in the scientific environment leads to a rapid increase in the flow of scientific data. Traditionally, data was stored in different storage locations within an organization or in the cloud. However, big data has made it a challenge to store and host all relevant data, including structured, semi-structured, and unstructured data. This was one of the reasons for the emergence of data lakes and their development (Gorelik, 2019).

The robotic conduct of scientific experiments is another promising direction. Burger et al (2020) provide an example implementation of a scientist robot that can autonomously perform experiments, analyze results, and decide what to do next. The robot moves through the laboratory thanks to a LIDAR detection system very similar to those used in autonomous vehicles and is programmed with coordinates for several workstations on which specific tasks are performed.

Scientists find virtual and augmented reality (VR and AR) technologies a promising tool in scientific research. VR replaces the physical landscape with a virtual one and thereby allows researchers to control experiments better. In essence, this means that VR will enable us to create a simulation of the environment with which we can interact without leaving our computers (Fox et al., 2020). For example, VR helps you observe the reactions of the human brain using the Virtual Maze Neuroscience app. This virtual environment allows neuroscientists to test how people respond to social interactions or use their spatial intelligence.

AR can meet users’ needs for the digital presentation of information in real-time by displaying this information in users' physical environment (Fataliyev & Mehdiyev, 2020). This environment will simplify the analysis of multidimensional datasets generated weekly or daily in a dynamic agronomic and climatological research environment (Israel & Scoble, 2016).

The use of digital twins is also becoming a promising direction in scientific research. For example, in a project known as Destination Earth, a digital twin of planet Earth has been created, which will be a virtual display of as many processes on the planet’s surface as possible, including the impact of humans on water, food, and energy systems. In addition, this will provide reliable information on extreme weather conditions and climate change (Voosen, 2020).

Häse et all. (2019) consider unmanned laboratories as an alternative to classical laboratories. Automated platforms based on machine learning, neurolinguistics programming, knowledge management, intelligent control, and BDA based on cloud services allow completely independent experiments in scientific laboratories. The creation of a self-contained laboratory is a multidisciplinary task that combines a wide variety of research areas. Machine learning and simulation techniques predict material properties and suggest new experiments, while robotics, AR and VR, and automated characterization techniques are used to conduct experiments and analyze results.

Fataliyev & Mehdiyev (2019b) consider modern trends in the use of CPS in the scientific community using various examples. Existing applications cover all stages from the collection, storage, processing, and analysis of research data to solving problems of science management.

Thus, the reviewed accompanying works confirm that Industry 4.0 has excellent potential for the development of science. At the same time, the reconstruction of science as a corporate environment of Science 4.0 based on Industry 4.0 solutions is relevant.

3. Integration of science and Industry 4.0

In the broadest sense, science is a highly specialized field of activity that provides objective knowledge about the world, including a human being. Apparently, its development began with the birth of civilization. Science arose in response to a certain need of mankind in the production and receipt of true, adequate knowledge about the world, and exists, having a very noticeable impact on the development of all spheres of public life (Il'yanovich, 2021). The evolution of science is directly related to the improvement and development of means and methods for solving such problems as the collection (registration) and storage of information, processing (logical and computational tools), and transfer (dissemination) of acquired knowledge.

It should be noted, that late 18th century and early 19th century, the process of intensive interaction between science and technology began, and a particular type of social development arised, which is commonly called scientific and technological progress. If we turn to the history of science, we see that in pre-industrial society, until the 18th century, science developed to some extent apart from the needs of society (Hey et al., 2009). The community's needs became the driving force that caused changes in science and contributed to the gradual transformation of science into an immediate productive force more and more. Thus, it can be assumed that the main achievements of science and technology formed the basis of industrial revolutions. At the same time, industrial revolutions stimulated new scientific directions, and there was an adaptation of science to the needs of society. Based on the analysis of the industrial revolutions that have taken place, we can propose the following classification of the stages of the evolution of science in conjunction with industrial revolutions (Table 1).

Table 1. The stages of the evolution of science since in the mid 18th century.

	Concept	History of development	Scientific and technical progress	Features of the development of science
1.	Industry 1.0/ Science 1.0	XVIII century	• Inventions of steam engines • Mechanical automation • The first sensors	• Experimental science • Development of engineering sciences • Application of sensors and mechanical devices in scientific experiments
2.	Industry 2.0/ Science 2.0	XIX and early XX centuries	• Electromagnetism • Telegraph, telephone, radio, and TV • Measuring devices (electricity, magnetism, wave) • Electrical automation/Mass production	• Theoretical science • Electricity, internal combustion engine, atomic physics, analog communication systems, aerodynamics • Scientific laboratories with electrical sensors and equipment • Electronic (audio and video lessons) and remote science promotion and educational technologies based on the widespread use of analog communication systems, radio broadcasting, and television
3.	Industry 3.0/ Science 3.0	From the 70s of the XX century	• Microelectronics, computer, PLC, robotics • Network technologies, Internet, WWW • Electronic automation	• Computational science (Computer modeling, computational experiments) • Development of cybernetics, informatics, genetics • Electronic (online) laboratories • Wide application of ICT, network technologies, and the Internet • Multidisciplinary, online scientific collaboration • Open Data, Open Science, Linked Open Data, Semantic Web
4.	Industry 4.0/ Science 4.0	XXI century	• IoT, CPS, AI, Big data • Smart automation • Collaborative robots	• Data-driven science • Data mining, Data Science, Computational science • Reconstruction of science with wide application of IoT, CPS, AI, and Big data technologies in scientific activity and science management

As follows from Table 1, four vectors of science development can be distinguished. In this sense, the fourth vector of science corresponds to the definition of Science 4.0, in which Industry 4.0 technologies are integrated into scientific research in various fields. This interpretation of Science 4.0 also contributes to the convergence of individual branches of knowledge and is characterized by the emergence of research at the intersection of disciplines, which, as they develop, develop into new subject areas.

Nevertheless, the priority of science and technology in industrial revolutions is still contested. Some scholars argue that skilled and talented artisans without scientific training were mainly responsible for essential inventions; others, referring to the James Watt steam engine, believe that the link between science and the most important designs of the period was fundamental (Gráda, 2016).

Here are some other examples. The invention of Henry Maudslay, who created a self-propelled caliper, made it possible to manufacture parts with an accuracy of a fraction of a millimeter, and laid the foundation for modern mechanical engineering (Gilbert, 1971). The emergence of machines caused the need for metal. Improvements and inventions by Henry Cort of puddling and rolling processes (1784) as the best way to convert coke pigs into wrought iron have gained progressive importance for that time (Harris, 1988). These processes required large amont of coal to be used in pig iron production, and coal mining became the leading industry in England during the first industrial revolution.

The scientific discoveries of Michael Faraday, James Clerk Maxwell, and other scientists in electromagnetism laid the foundation for the production of electricity, electric motors, lighting fixtures, and more (Baigrie, 2007).

It should be noted that inventions of the second industrial revolution, such as the phone or radio, had a significant impact on accelerating the exchange of information in society (Huurdeman, 2003). And thus, they also contributed to the dissemination of new ideas and knowledge both in the scientific community and in society as a whole. The emergence of opportunities for rapid transmission of information over long distances coincided with a period of active development of the natural sciences.

4. Forming the Science 4.0

4.1. E-Science is a technology platform for Science 4.0

On whole, in scientific activity or research, a big role is played by gathering, storage, processing, transferring, and the analysis of the data. In turn, the data is classified as the data of supervision, the experimental, and the settlement date. On their basis, the scientific description, forecasting based on models, the intellectual organization of scientific activity, and management of science are carried out. In contemporary history, digital technologies have had a significant impact on all stages of scientific activity, which basic elements of steel the information and ICT. So already in the forties of the last century, K. Zuse experimented with the aerodynamics of aircraft. He fed the signals from hundreds of sensors into the Z3 programmable computer, where the most efficient airfoils were calculated (Copeland & Sommaruga, 2015). In the future, the integration of traditional scientific activities with the widespread use of computers became more accessible due to the development of network technologies. The beginning of such integration can be seen in the example of the ARPANET telecommunications network of the Defense Advanced Research Projects Agency, which became the prototype of the modern Internet (Roberts, 1988).

New methods of collaborative research, including computer simulation and the organization of a virtual experimental environment, are specified in the e-Science program launched in the UK in 2000 (Hey & Trefethen, 2002).

In a broader sense, e-Science is based on two main fundamental tasks: the restructuring of the existing scientific environment by the requirements of the information society and the use of ICT in this environment (Alguliyev et al., 2015). Solving these problems requires an integrated approach that involves monitoring the use of ICT in scientific activities, monitoring and managing research, ensuring information security, and developing scientific, theoretical, and practical foundations for the introduction of electronic technologies. The solution to these tasks will allow achieving the following results (concerning the academic community of the Republic of Azerbaijan):

1.The national program "e-Science" will be brought into line with world standards as the study of world experience, adjustments to informatization of science, based on monitoring, and improvement of the regulatory framework.

2.Accelerated development of the material and technical base; creation of local networks of scientific organizations and provision of high-speed Internet; creation of a unified scientific network connecting scientific organizations of the AR, and its integration with international scientific networks.

3.Development of a security strategy.

4.Creation of information resources for various purposes.

5.Solutions for the organization of a researcher's workplace directly related to the use of ICT in scientific activities and tasks covering the activities of research teams.

6.Creation of new scientific relations based on the online environment in various fields of science.

7.Integration with international scientific organizations.

8.Formation of scientific and information spaces.

9.Creation of computing tools based on supercomputers, grid, and cloud technologies to solve problems requiring significant computing and storage resources.

10. Issues of commercialization of science, etc.

11. Implementation of the training of scientific personnel in modern ICT and the organization of technical and software services.

Thus, e-Science is perceived as a complex system with technical and technological components such as infrastructure, generation, collection, storage, processing, retrieval, analysis, transmission, presentation of data, etc.

Summarizing the above, we can conclude that the e-Science model proposed by Alguliyev et al. (2015) can be accepted as the technical and technological basis of Science 4.0.

4.2. Conceptual issues of the problem of the Science 4.0 forming

This section analyzes the possibilities of Industry 4.0 when creating new organizational structures for scientific activity. Along with the traditional research structures, virtual scientific institutions, scientific clusters, scientific networks, and science parks have been made. With the development of technology, the emergence of such new quality structures will continue. Science 4.0 finds simple solutions to technical, technological, economic, and other problems.

Science 4.0 is viewed as a corporate environment with appropriate physical infrastructure: telecommunications networks, data centers, research laboratories, buildings, electricity, logistics, etc. They must provide:

•for buildings – uninterrupted power supply and water supply; climate control; access control; building security and video surveillance; material and equipment management; equipment monitoring; building management, hazard detection, and warning, etc.;

•maintenance of network resources, facilities, and equipment; network monitoring and cybersecurity; electronic services; continuous diagnostics, etc.;

•management and security of information support of science;

•integration of Industry 4.0 into the research environment.

Such an infrastructure can be created based on the Industry 4.0 smart city platform. It should be noted that similar trends are typical for a smart campus, consisting of complex infrastructures such as classrooms, libraries, laboratories, faculties, and computer systems, where the university community can develop activities for their learning (Villegas-Ch, 2019).

Based on the above, the following conceptual model of Science 4.0 can be proposed as shown in Fig.1.

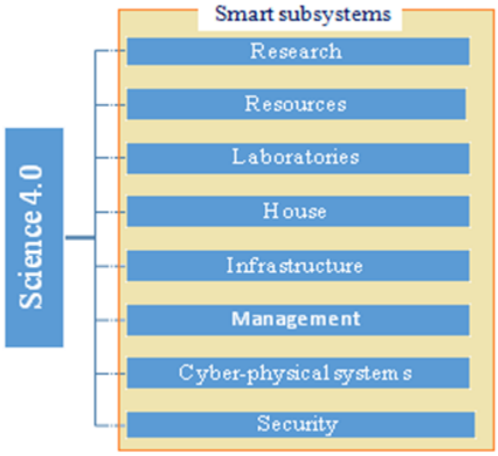

Fig. 1. Generalized conceptual model of Science 4.0

Smart objects can be dynamically reconfigured for high flexibility, while BDA can provide global feedback and coordination for increased efficiency. Thus, it will allow practical problem solving within the framework of Science 4.0.

It should be noted that the formation of Science 4.0 based on a single concept is a complex problem and requires financial, regulatory, technical, and technological support, and therefore should be carried out in stages. Here, should be considered followings:

•development of network and computing infrastructure, data warehouses following new requirements;

•introduction of a new generation of intelligent sensors, actuators, wireless sensor networks, AI amplifiers, graphics processors, parallel processing processors, etc.;

•specialized software;

•development of systems for their purpose;

Moreover, Science 4.0 actualizes issues of cybersecurity, personal data protection, and such a sensitive topic in the scientific community as plagiarism and priority in research. Blockchain technology can solve these problems. Furthermore, blockchain will make large parts of the research cycle open to scientific self-correction. This new approach to reproducibility in science has the potential to "cut waste and make more research results true" (Van Rossum, 2017; Bartling, 2019).

Thus, summarizing the analysis carried out, it is possible to propose such a form of the modern scientific environment, which should represent the following fundamental points:

•Automated knowledge extraction.

•Solving problems of priority and plagiarism.

•Automated science experiment.

•Communications, computing resources, data storage.

•Virtual environment, mathematical modeling.

•e-Science, open science, citizen science.

•Smart management.

•Smart infrastructure.

•Cyber resilience, cyber security.

Thus, as IoT, CPS, AI and other intelligent solutions of new ICTs become effective tools of modern scientific research, Science 4.0 is increasingly acquiring such characteristic features of Industry 4.0 as interoperability, modularity, flexibility, virtualization, decentralization, optimized adoption real-time solutions, etc.

5. Conclusion

In contrast to the past, when science was limited in scope, modern science includes many disciplines and is characterized by the breadth of research. The boundaries of scientific research have expanded due to the massive application of current information and communication technologies. IoT, CPS, AI, cloud computing, Big data, and intelligent solutions in science have contributed to new trends in research, and science management and have influenced the interaction between science and society. The technologies now available to scientists and the automated measurement of the world (observation of bacteria with microscopes, chemical experiments in the laboratory, observation of galaxies through telescopes, etc.) also enable scientific description and prediction based on models of processes and their networks. This article developed conceptual issues of Science 4.0 formation based on the e-Science platform according to Industry 4.0. Classification of stages in the development of science concerning the industrial revolutions occurred was proposed. Analysis of related works on the application of leading technologies of Industry 4.0 in science, such as IoT, CPS, AI, Big data, etc., confirmed that Industry 4.0 opened up new prospects for the development of science. Reconstruction of science as a corporate environment within the framework of a unified concept of Science 4.0 based on Industry 4.0 solutions will increase the efficiency of scientific activities and support solutions for the operational management of science. Future research will discuss the integrated applications of technology in Science 4.0 in more detail to best meet the needs of the scientific communities.

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