

Human Factor as a Determinant of Technology Development and Economic Growth in the Period of Digital Transformation

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Abstract: The active deepening of transformation processes has led not only to the introduction of digital technologies, but also significantly increased the role of the human factor. The deployment of the fourth industrial revolution has contributed to the formation of a new technological paradigm, which digital technologies act as the basis for the economics' modernization. The driving force of these processes remains a person who not only produces technological innovations, but also effectively uses them. In this context, special attention is paid to the study of theoretical aspects of the relationship between the human factor and human capital, as well as empirical confirmation of the influence of a person on the country's innovative capacity. Accordingly, the purpose was to reveal the relationship between human capital and the human factor, as well as to clarify their significance in the formation of innovative potential and economic growth in the context of the digital transformation. The various methods of cognition were used, including comparative analysis, graphic method, system approach and correlation analysis. As a result of the study, it was found that behavioral factors as the basis of the human factor cannot be considered in isolation, because they are formed based on human capital and reflect its practical implementation. Only in the interaction two components is the human potential revealed, which can ensure the stability and effectiveness of social development. The correlation analysis conducted confirmed the presence of a close relationship between the level of human capital and the innovative capacity. It was found that improving the quality of human capital contributes to strengthening the innovative potential and advancing the state in the world rankings of innovative development. This indicates that human capital acts as a system-forming factor of innovation processes and determines the strategic opportunities for economic growth.

1 INTRODUCTION

The modern development of society is determined by active transformational processes that cause the rapid spread of digital technologies, which implementation causes a change in the technical and technological structure, modification of the mechanisms for achieving economic growth and contributes to the gradual increase in the role of the human factor as a key determinant of development. Taking into account such changes, it can be stated that today the national economies of the world's leading countries are in a state of digital modernization, which occurs under the influence of the fourth industrial revolution and

involves the widespread use of Big Data, artificial intelligence, machine learning, the Internet of Things, analytics, automated systems and robotics, which radically change the characteristics of management, tools and mechanisms for achieving goals, forming new conditions for ensuring sustainable economic development.

These processes bring to the fore a person and his human capital with all its qualitative characteristics, which become a driver kind of innovation creation and their transformation into effective technological solutions. Indeed, only a person as a carrier and owner of skills, abilities, knowledge and innovative potential in general, can generate technological

innovations and subsequently transform them into effective tools, which will allow to increase the competitiveness of the national economy and strengthen its position on the world stage.

Even though digital technologies are a kind of basis for the modernization of the economy and society, their effective use is determined by human. Accordingly, technologies are not a self-sufficient source of development, they only play the role of a tool (a modernized tool of labor), which effective use depends on the level of competencies, value system, worldview and culture of its users. Thus, in interaction with technologies, a person can act as both a direct user and a developer or creator of new solutions. Therefore, it is human who not only generates innovations and creates new technological solutions, but also sets the vector of their use and further development. The consequences of this process can be both positive, which is manifested in promoting the growth of productivity and efficiency, and have destructive manifestations, among which we highlight the aggravation of the risks of digital inequality, the displacement of traditional forms of labor by automated systems, the growth of social disunity or structural fragmentation of society.

The outlined trends confirm the need for an in-depth scientific analysis for the role of the human factor in the period of technological change. We believe that the results of such studies can serve as the basis for the formation of effective state policy in the field of digital economy development, the development of human capital and its adaptation to the new requirements of the time, as well as for the development of new models of human-technology interaction. Therefore, the comprehensive disclosure of the human factor as a determinant of technology development in the period of digital transformation of the national economy is an extremely relevant and mature issue in both theoretical and practical dimensions.

2 LITERATURE REVIEW

Recent trends in economic progress in developed countries have led to an increase in interest among the scientific and research community in substantiating how digital technologies change business, economics, education and society. In this aspect, special importance is attached to the disclosure of the issue for the human factor in the context of digital transformation, which is reflected in numerous theoretical and empirical publications. In particular, such developments are devoted to the analysis for the

role of human capital in the implementation and using digital technologies; identifying the features of the interaction between humans and technologies; studying the processes of forming digital culture, consciousness, thinking and qualitative characteristics of human capital, which are due to technological changes; revealing organizational, managerial and institutional aspects aimed at the development of the human factor.

Thus, recently, there has been an increase in the number of scientific publications that widely use keywords such as "digital skills", "human factor in digital transformation", "ICT usage", "labor structure in digital economy". Among them, the most popular research category is digital skills, which is primarily due to their decisive importance in ensuring the efficiency of the functioning for the digital economy and the competitiveness of human capital. In particular, the scientific work of Ester van Laar [1] deserves attention, which emphasizes that innovations begin with a person. In the conditions of the dynamic development of the modern knowledge economy, it is digital skills and 21st century skills, which the authors consciously distinguish, that determine the competitiveness of the organization and its innovative potential. It is also worth noting separately that the presented understanding of 21st century skills is broader than digital, which is due to the inclusion of ethical awareness, cultural awareness, flexibility, self-direction and lifelong learning in their composition. It is especially appropriate to emphasize the results of the study by Tsyra O. [6], which states that digital transformation changes the requirements for human skills, abilities and knowledge. This, in turn, actualizes the development of digital skills, which level depends on the development of the national economy and its competitiveness, as well as the activity of implementing and spreading innovative activities.

In Qi Xiong's study [2], digital transformation is defined not only as a technological replacement, but as a process of achieving efficiency, which becomes possible due to the complementarity and integration of human and machine. The authors also emphasize that the model's development of such interaction is due to the widespread use of intelligent systems, in particular robots, computers, artificial intelligence algorithms and automated control systems.

In general, an approach that combines the analysis of human capital and digital technologies as interrelated factors of economic development is becoming increasingly widespread in scientific research. As an example, we can cite the work of Popelo O. [8], which reveals the role of digital

technologies in balancing the labor market and determines the importance of digitalization in the formation of new opportunities for professional human realization. We believe that such an approach allows us to consider a person not only as a user of new technologies, but also as an active subject capable of generating trajectories of economic transformation.

In addition, a significant number of review studies on this issue deserve attention. In particular, the works of Maria Anna Lykourantzou [3] emphasize the human factor as a factor that allows achieving success in digital transformation projects. The work of Pablo Reyes-Cornejo [4] records the growth of scientific interest in substantiating the role of flexible skills in the processes of change caused by the spread of digital technologies and emphasizes the analysis of digital transformation through the prism of human resource management in the context of personnel policy, which is considered as the basis for the formation of new skills. Another work by Daniela-Aida Ionescu [5] emphasizes that digital transformation encompasses two complementary dimensions: technological, which provides tools; human, which determines the reality and effectiveness of changes. The authors conclude that the long-term success of digital transformation directly depends on managing the process of integrating technology with human potential. The systematic review presented in the study by Jelena Crnobrnja [7] identifies the feasibility of using a systemic approach to provide a more comprehensive analysis of human-centricity in the context of Digital Transformation and Industry 5.0. Special attention is also paid to the issue of harmonizing technological development with human values, safety, ergonomics, skills development and ensuring employee well-being.

Thus, a review of modern scientific developments shows that a person is a key condition for the development of technologies during the period of digital transformation of the national economy. After all, firstly, it is a person who becomes the central element of the digital environment, and the effectiveness of integrating innovations into various spheres of social production depends on the level of knowledge, skills, competencies and flexibility of adaptation. Secondly, coordinating the interaction of a person and technology requires not only technical, but also social, ethical and organizational solutions that ensure the harmonious coexistence of artificial intelligence, automation and human capabilities. Thirdly, modern research emphasizes the need to

clearly define the role of a person in the development and use of new technologies, from a creative subject capable of generating innovative ideas to a bearer of values, security and responsibility in the digital space. We believe that in this context, further scientific research should be aimed at using interdisciplinary and systemic approaches that will reveal the human factor as the leading determinant of the development and use of modern technologies during the period of digital transformation of the national economy.

3 SYSTEMIC INTERCONNECTIONS OF THE HUMAN FACTOR AND HUMAN CAPITAL

In our study, we proceed from the premise that the human factor is a derivative manifestation of human capital, even though, as a rule, they are considered in different analytical dimensions. The human factor is mostly used in socio-psychological and organizational-management aspects, which allow to focus on the personal characteristics and behavioral reactions of the individual. Human capital is one of the most studied economic categories of modernity, reflecting the qualitative parameters of a person in the form of a resource that can be accumulated, multiplied and converted into added value. However, there is an internal connection between these categories: human capital is basic, and the human factor is a superstructure or a derivative category that reflects the practical use of the accumulated potential.

We believe that the most generally accepted definition of "human capital" is the approach presented by the OECD, according to "Human capital can be broadly defined as the stock of knowledge, skills and other personal characteristics embodied in people that helps them to be productive" [10]. That is, human capital accumulates in knowledge, skills, qualifications, professional experience, appropriate health status, cultural level and value system, and forms the potential for personal development. However, such potential does not guarantee the effective course of socio-economic processes. Since it acquires real significance only when it is reflected in the practical activities of a person. Accordingly, at this stage, human capital is transformed into a factor or force that directly affects the effectiveness of production, management or social relations (Fig. 1).

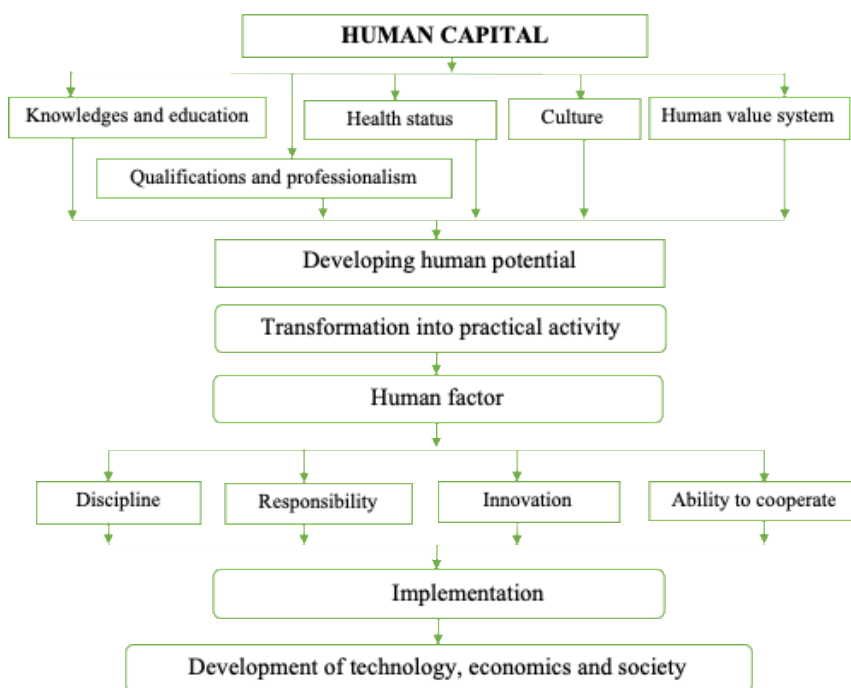


Figure 1: Structure and components of human capital as the basis for personal development potential.

Therefore, discipline, responsibility, innovation and teamwork, which are attributed to the manifestations of the human factor, can be interpreted as secondary, derived from the main components of human capital. The education level and culture determine organization and the ability to comply with norms and rules; professional experience and qualifications become the basis for responsibility and risk-taking in decision-making, and intellectual abilities form the basis for creativity and innovation.

The definition of the human factor as a derivative manifestation of human capital allows us to rethink the effectiveness of socio-economic development. In this context, not only the quantitative parameters of human capital accumulation become important, but also the quality of its implementation in the form of specific actions and results. That is, when assessing the human factor and its importance in the development of technologies and the economic system, it is advisable to analyze not only individual behavioral characteristics, but also those social investments that determined their emergence: education, professional training, cultural environment, education system. In such an interpretation, the human factor acts as a key link between the potential resources embedded in human capital and the real productivity of social development.

In addition, the coherence of human capital and the human factor creates the prerequisites not only for achieving performance, but also for the development of innovations and modern digital technologies. After all, as defined Aleknavičiūtė, R. "the main purpose of human capital is to create innovations: to generate new ideas, to create new products, services, or goods, to improve existing products, services, or goods, to establish new business processes and so on" [11, p. 116].

Therefore, in modern conditions, behavioral factors as components of the human factor cannot be considered as self-sufficient or separate manifestations, since they are formed based on human capital and function as its superstructure, which determines their stability and effectiveness. Only in the unity of human capital and the human factor is the true potential of a person and society revealed, since the accumulated knowledge, skills and values have meaning only when they are transformed into specific actions and behavioral manifestations. At the same time, the human factor itself cannot be self-sufficient without a foundation in the form of formed capital. Thus, the effectiveness and success of economic development is determined not by the isolated existence of these categories, but by their harmonious interaction, where capital appears as a foundation, and the factor as its effective reflection in practical activity.

4 PERSON AS THE DRIVING FORCE OF TECHNOLOGICAL CHANGES AND NATIONAL DEVELOPMENT

Throughout history, human has been the main initiator and creator of technological change. In general, no technological variable or innovation arises by itself but is always the result of human reason and imagination, which are primarily aimed at meeting growing needs. The evolution of tools and labour tools from the first stone products to modern digital technologies demonstrates human's constant desire to facilitate physical and mental labour, expand his opportunities for creativity and self-education, as well as increase the level of well-being and quality of life. Accordingly, each new technology arises because of human ingenuity and initiative, the desire to improve living conditions, forming not only a new mechanism for performing actions, but also new ways of thinking, interacting with society and perceiving the world around us.

As Mykola Berdyaev rightly noted, "any tool created by human is directed not only outwardly at the objects of activity, but also inside the subject itself" [9]. It is thanks to the interaction of man and technology that new stages of the evolution of mankind are formed: the transition from the Stone Age to the Iron Age, from agrarian to industrial civilization, from industrial to modern information society. However, we believe that in the outlined process, the key importance belongs to human, since his creativity, initiative and ability to innovate determine the direction and pace of development. Human not only creates equipment and technologies, but also gives them meaning, determines the directions of development and the scale of use. And technologies arise only as tools necessary for the implementation of human ideas, and not as independent drivers of progress. That is, human sets a goal, chooses the path to achieve it and adapts technological solutions to social, cultural and economic needs.

In modern scientific discussion, it is increasingly assumed that the level of human development, which is reflected in the accumulated human capital, directly affects the technological progress of the state and determines its position in global economic

competition. Human capital, embodied in knowledge, educational level, professional training, health status and the ability to learn throughout life, forms the basis for the creation and implementation of new technologies. Accordingly, the growth of the educational and intellectual potential of society increases the country's ability to generate innovations, which is reflected in such indicators as the Global Innovation Index, Global Competitiveness Index, Digital Economy and Society Index, Knowledge Economy Index and others.

Based on the analysis of the Global Innovation Index of European countries, we will prove the presence of a direct relationship between the level of human capital development and the innovative capacity of the state. The focus on this index is not accidental, since it comprehensively reflects the ability of the country to create, develop and implement innovations, as well as to effectively use human, intellectual and technological resources. Considering the above considerations, it is advisable to move from theoretical provisions to empirical analysis, which will help to find out to what extent the development of human capital correlates with innovation results and economic growth. We believe that such an approach will allow to identify the systemic impact of the human factor on the state's ability to produce new technologies and integrate them into socio-economic practice. Thus, the main research hypothesis of the analysis is that a higher level of human capital development contributes to an increase in innovative capacity, which, in turn, has a positive effect on the introduction and technologies use, as well as macroeconomic indicators that determine the state of development of the country's economics.

Let us analyze the Global Innovation Index and its components among European countries in 2025 (Fig. 2). The trend of a decrease in all components of the studied index as the transition from highly developed countries to less developed ones is obvious. The highest indicators for all components are observed in Switzerland, Sweden, Great Britain, Finland, the Netherlands and Denmark, which are included in the TOP 10 of this rating. It is these countries that demonstrate a balanced development of the educational and scientific sphere, institutional environment and business infrastructure, which ensures a positive innovation dynamics of development.

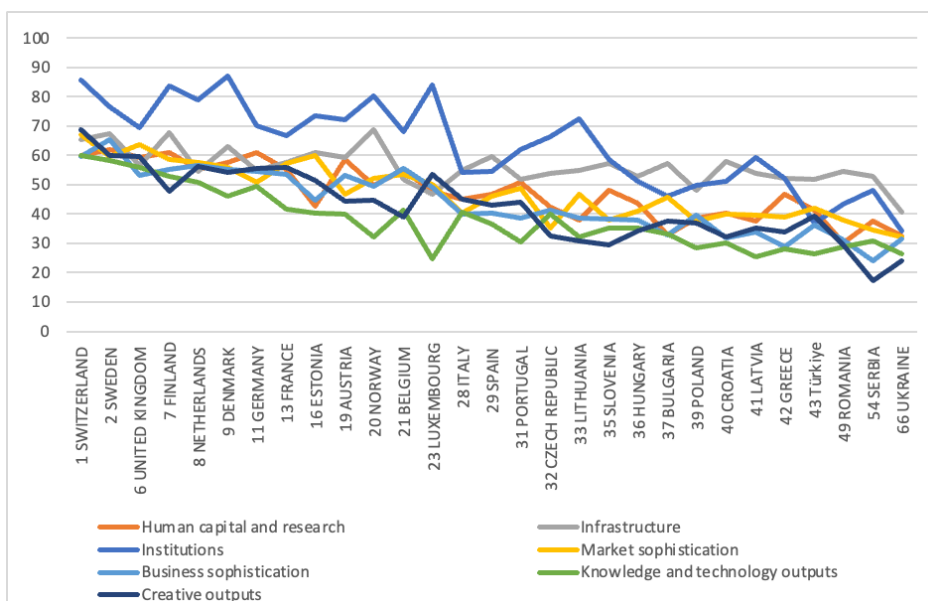


Figure 2: Components of the Global Innovation Index among European countries in 2025 [12].

The countries of Central and Eastern Europe, in particular the Czech Republic, Poland, Hungary, Bulgaria, and Croatia, are characterized by a moderate level of human capital development and relatively lower results. This indicates the presence of potential for innovative growth, which has not yet been fully realized. However, addressing various structural and managerial barriers can become a kind of impetus for activating innovative potential, transforming scientific and educational achievements into real technological products, and increasing the competitiveness of the national economy at the global level. The lowest indicators of European countries are Romania, Serbia, and Ukraine, which reflects both limited resources for scientific research and insufficient integration of the results of educational and scientific activities into the sphere of technological and creative production. However, it is worth noting that over the past four years, Ukraine's position in the studied rating has significantly deteriorated in 2025 it occupies 66th place against 45th in 2020. We believe that the main reason for this decline is the deployment of active military operations on its territory. As a result, a significant part of the country's intellectual potential is used not to ensure technological development, but to meet the needs of the defense-industrial complex.

In addition, the full-scale military aggression in Ukraine further deepened the existing demographic crisis, which has a direct impact on human capital. Thus, according to international experts, the population of Ukraine decreased by approximately 10

million people during the war years [13], which is the total effect of migration, military losses and a decrease in the birth rate. According to UNHCR, as of February 2025, 6.3 million Ukrainians received refugee status in European countries, and about 560 thousand outside Europe [14]. As a result, European countries received additional labor potential in the form of qualified specialists who were trained within the Ukrainian education system, without the need for significant additional investments in their professional training. In contrast, such demographic losses have negative consequences for Ukraine's innovative capacity, including a decrease in the number of young scientists, researchers, and higher education graduates, as well as the loss of potential labor force and part of the creative potential.

Thus, the above graphical analysis allows to state that countries with high investments in education, research and development of human potential occupy leading positions in world innovation rankings, while the deficit of human capital or improper attitude to its formation and development significantly limits the opportunities for economic and technological development.

The Global Innovation Index is an integral indicator consisting of seven main components, each of which reflects a separate aspect of innovation potential and development. To assess the relationship (linear dependence) between the country's place in the overall GII ranking and its values for individual components (sub-indices), we will determine the

Pearson correlation coefficient (r), which is calculated by the (1):

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \tag{1}$$

where:

x_i – the value of a separate component of the Global Innovation Index;

y_i – value of the overall rating or integral index;

\bar{x} and \bar{y} – average values of the corresponding indicators.

The resulting Pearson coefficient can vary from – 1 to + 1, which allows us to determine the nature and strength of the relationship, in particular:

- 1) if r tends to + 1, then there is a strong direct correlation (an increase in the indicator indicates an increase in the rating position). Since a higher place in the rating (a larger number) means a worse result, then such a dependence indicates a negative impact of the indicator on the overall level of innovative development;
- 2) if r tends to – 1, then there is a strong inverse correlation (an increase in the indicator is accompanied by a decrease in the rating position or the country's promotion to the top positions of the rating). In such a situation, we can say that the indicator has a positive impact on the state's innovative capacity;
- 3) if r approaches 0, then the relationship is insignificant or absent.

The results of the correlation analysis (Table 1) indicate the presence of stable and mostly strong inverse relationships between the overall rating of the

country in the Global Innovation Index and most of its components. That is, the improvement of indicators for individual components of the index (each of which has its own weight) is accompanied by a decrease in the country's ranking, that is, advancement to the top positions in the global innovation space. In addition, the analysis data confirm the previously put forward hypothesis that there is a close relationship between the level of human capital and the innovative capacity of countries. Accordingly, human capital should be defined as a system-forming factor of innovative development. Therefore, promoting the development of human capital is a necessary condition for the growth of innovative potential.

Thus, human capital and the human factor are interconnected components of a single socio-economic mechanism that determines the dynamics of innovative development. Human capital forms an intellectual, creative and value basis for the creation of new knowledge and technologies, and the human factor reflects more behavioral, motivational and cultural aspects of the implementation of this potential in the real economic environment. Based on their interaction, knowledge is transformed into practical innovations, which ensures increased production efficiency, contributes to the growth of key macroeconomic indicators and strengthens the country's competitiveness. Therefore, the development of human capital in combination with the activation of the human factor is a determining condition for technological progress and the sustainability of national development.

Table 1: The relationship between a country's position in the Global Innovation Index and its individual components.

Component of GII	Correlation coefficient – r	Degree of dependence
Institutions	–0,864091574	Very strong correlation. The more effective the institutional, regulatory and business environment, the higher country ranks in innovation rankings.
Human capital and research	–0,88135353	One of the strongest links. Accordingly, human capital is important in shaping innovation capacity.
Infrastructure	–0,674301895	Moderately strong relationship. Infrastructure, including the level of ICT development, is important, but not as important as other components.
Market sophistication	–0,913429169	Very strong dependence. Indeed, countries with a developed financial system and a favourable investment climate occupy higher positions in the ranking.
Business sophistication	–0,929227308	The highest connection. Thus, business innovation, the ability to implement new solutions, and cooperation with the scientific community are key to determining a country's position in the ranking. However, it is worth noting that such elements are mainly determined by the already formed human capital.
Knowledge and technology outputs	–0,85110839	Strong correlation. The more knowledge and technological output a country produces, the more innovative it is.
Creative outputs	–0,911598208	Very strong dependence. Accordingly, the development of the creative industry is an important factor in the overall innovation potential.

5 CONCLUSIONS

Despite the rapid development of technology, which has been especially noticeable in recent decades, it is people who remain the main source of innovation and progress. We agree that modern equipment and machines can work faster and more accurately than people, but they are not able to generate new ideas, produce innovations and improve management decisions. Accordingly, only a person as a carrier of unique human capital can form the basis of scientific and technological evolution and determine the vector of its innovative development, which is confirmed by the results of the correlation analysis. Precisely because the conclusions of the study can be used in a practical sense, in the process of developing national strategies for the development of human capital as a strategic resource of the digital society.

So, in the conditions of digital transformation, the development of technologies and the economic growth of society depends on how effectively human potential is revealed and realized. After all, thanks to the latter, knowledge is transformed into practical results, improvement or creation of new products and technologies, and the formation of competitive advantages. In general, it is advisable to define a person not only as a determinant of economic growth, but also as an intellectual basis for civilizational progress, capable of initiating changes and at the same time ensuring the harmonization of technological and social development. We believe that further scientific research within this area should be aimed at developing an effective mechanism not only for managing the development of human capital, but also for its implementation in various sectors of the national economy.

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