The Dualistic Nature of Technological Convergence and Human Resources

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Abstract The convergence of technologies significantly changes both the patterns of production and the very nature of socio-economic systems. The need for constant knowledge updating and the continuity of the education process are becoming one of the key factors in achieving social harmony in society. However, uneven economic and technological development poses certain threats to both employment and production systems that create economic benefits in the form of goods or services. The paper shows the dualistic nature of the advance of technology and formation of human capital, when constantly and rapidly updating technologies may contribute to the ousting of mainly middle-skilled employees from the labor market. A mean of overcoming this situation is the extensive training of engineering personnel and qualified specialists capable of working in the environment of man–machine intelligent systems. Examples include the authors' projections on the distribution of employees of various skill levels in the US economy in the 2030s.

Keywords Convergence of technologies · Human resources · Skill level and distribution of employees

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1 Introduction

Technological progress (TP) has always been accompanied by the automation of human labor for certain professions, but at the same time, it has generated new activities by creating new jobs. Thus, on the one hand, machines replaced people, displacing them from performing certain tasks, and on the other hand, they complemented people in a more productive solution of other tasks, increasing the demand for human labor in other activities and possibly elsewhere. In the twentieth century, the complementing feature of the machines was much stronger than the substitutional one, so more new jobs were always created than were destroyed by technological substitution. However, after the 1980s, with the onset of the information age, as D. Acemoglu and P. Restrepo have discovered (Acemoglu & Restrepo, 2017), the substitutional force of technological progress outstripped the complementary one and, as a result, the demand for labor started to decline throughout the economy. In the first half of the twenty-first century, the same process will take place due to powerful clusters of converged NBIC technologies, as well as digital technologies and platforms. Due to their inherent property of mutual convergence, NBIC technologies generate a significant synergistic effect that may significantly increase the total factor productivity (TFP), i.e., accelerate technical progress. The same refers to the digital technology cluster. ICTs themselves are very encouraging as they greatly facilitate the process of creating innovations by facilitating the flow of ideas (Glaeser, 2014). TP, on the other hand, takes place most naturally and spreads unhindered at the presence of inclusive political and economic institutions. The latter are currently expanding and deepening in developed countries; they are also being formed in developing countries, narrowing the space of extractive institutions (Acemoglu, 2014).

D. Susskind shows very convincingly that technological unemployment, which originated in the information age, will only grow in the digital age (Susskind, 2020). Technological unemployment was more of a frictional nature in the past, i.e., a person could not take advantage of available jobs for a number of reasons, such as inconsistencies in skills or residence, as well as status discrepancies. According to D. Susskind, structural, technological unemployment will prevail in the future due to the widespread use of intelligent machines (IM) when there are simply not enough jobs for all people ready to work (Susskind, 2020, Ch.7). Moreover, medium-skilled jobs will be the first to disappear. It turned out that middle-skilled workers solve routine tasks that are easy to automate with intelligent machines (IM). Any routine work, including routine intellectual work, may now be automated by robots or computers with elements of artificial intelligence (AI), while such automation is becoming ever cheaper.

In the 1980s, automation was carried out mainly through the introduction of robotics and it replaced low-skilled labor above all, increasing the demand for highly skilled and highly paid labor; but then, with the introduction of IM, its influence on the labor market changed dramatically, and the demand for cheap, but non-routine labor that was difficult to automate or that was unprofitable from an economic point of view started to grow as well. As a result, employment has begun to concentrate in both the most and the least paid segments of the labor force, and the number of middle-paid jobs has begun to decrease rapidly. This phenomenon was called "workforce polarization" (Brynjolfsson & McAfee, 2014), and it has caused great concerns among economists, as it led to an increase in income inequality in society. Today, as predicted, the wash-out of various occupations requiring medium qualifications has accelerated in developed countries as a result of the substitution of the respective jobs by IM (Acemoglu, 2014). Thus, technological unemployment will primarily affect middle-skilled workers, encouraging them to improve their skills.

Technological unemployment will proceed against the background of demographic factors. There are three important conclusions from the UN's projections of the world's population growth: firstly, the world's population will continue to grow for a long period of time, and then it will stabilize; secondly, the population will keep aging in the developed and advanced countries; thirdly, our planet can easily accept this increased population, and there is no reason to worry about any acute resource shortages or conflicts associated with overpopulation (Acemoglu, 2014; Deaton, 2014; Glaeser, 2014; Roth, 2014). The development of labor-saving technologies may well solve the problem of labor shortages due to the aging population. There was no scarcity of natural resources in the twentieth century, labor was a limited economic resource, and technical progress was aimed at creating predominantly labor-saving technologies. As a result, for example, agriculture and industry have achieved such high levels of productivity that only 2–3% and 10–15% of workers in developed countries work nowadays in these basic sectors of the economy, respectively. Recently, even in developing countries, there has been a decline in agricultural employment and its expansion in the services sector. In the twenty-first century, the agricultural sector and industrial production will continue to shrink, giving way to the service sector (Solow, 2014).

Further development of labor-saving technologies may have a very positive effect on the socio-economic development of industrialized countries, as well as such advanced countries as China, where population aging is combined with the intensive development of robotics and IM. Population aging in developed countries no longer means that economic growth there will stop due to a shrinking labor force. They may now be successfully replaced by advanced robots and intelligent computers with AI elements. The strength of developed countries is their high level of human capital development, which may become the basis for economic growth even with a shrinking population. In fact, the development and production of IMs require a range of scientific knowledge and relevant labor skills, as well as the high-tech infrastructure available in developed countries. As a consequence of the above factors, labor immigration to the developed countries from the developing ones is no longer a prerequisite for their economic growth.

2 NBIC Technologies as an Example of Technological Convergence

The active process of technological convergence, which started in the late twentieth and early twenty-first century, means not only the mutual influence but also the interpenetration of technologies, when the boundaries between individual technologies are erased, leading to the final results within the framework of interdisciplinary research and development at the intersection of various fields of science and technology. Currently, technological convergence is particularly evident at the junction of NBIC technologies.

The concept of converging technologies was developed by experts from a number of EU and G8 countries in the early twenty-fisrt century. The concept was based on the principle of a "synergistic combination of four scientific and technological fields" developing with exceptional dynamism. These are (1) nanoscience and nanotechnology; (2) biotechnology and biomedicine, including genetic engineering; (3) information technology, including the latest computer and communication technologies; and (4) cognitive sciences that incorporate neuroscience and cognitive technologies. These areas have received the term NBIC technologies or NBIC convergence, which are generally accepted and used in world practice.

In addition to the process of technological convergence, an equally important synergistic process is underway. Synergetics is a scientific direction that studies the phenomena of self-organization, representing the theory of describing processes accompanied by a reciprocal, "cooperative effect." Instead of the concept of "synergy," the "synergetic effect" term is sometimes used, which characterizes the increase in the efficiency of activities as a result of integration and convergence of technologies. It is the synergy of NBIC technologies that will have a dramatic impact on the twenty-first century economy.

Distinctive features of NBIC convergence are:

- Intensive interaction between these specified scientific and technological areas
- Significant synergistic effect
- Qualitative growth of technological capabilities of individual and social development of a person

A synergistic effect caused by a very intensive interaction and mutual influence of new basic technologies, their cooperative action or, in other words, caused by NBIC convergence, may be so strong that its contribution to the increase in the aggregate productivity of factors will become decisive and the economic growth rates in developed countries may approach the record values of 4–5% again.

The world around us will change rapidly and dramatically with the widespread use of digital technologies and robotics. Unfortunately, these changes bring not only extraordinary new opportunities but great risks as well. In this regard, active creative work is required to develop effective social innovations in order to painlessly overcome the negative consequences of the new age of intelligent automation of production and management. As for the threat of technological unemployment and technological shift in the demand for labor towards high qualifications, these challenges should rely on "massive high-quality education" (Susskind, 2020). Today, this is truly the best response to the looming threat of technological unemployment for the middle class.

3 Formation of Human Resource in the Context of Convergence of Technologies

Technological progress in the twentieth century generally encouraged advanced training, which made the labor of educated employees more valuable. Nowadays, education is still one of the best investments in the future for young people (Susskind, 2020). Prominent experts believe that it is necessary to invest in quality education at all levels (Deaton, 2014), and it is important to revive the priority of such subjects as mathematics, science, and engineering specialties (Dixit, 2014). An age of competition between qualified professionals and machines in the face of an advanced robot or intelligent computer is coming. For example, the competition between low-paid labor and robotics in the production of electronic devices is best known. Modern gadgets and computers may be produced by both humans and robots. Therefore, they are produced in China, where low-paid labor is still very common. But only robots will be able to produce ICTs based on nanochips and biochips. Therefore, the education system should train people in the future to perform only those tasks in which IM will complement them rather than replace them. This is one of the directions of modernizing the current education system.

Requirements for engineering education are determined by the economic model of the state, the structure of its real economy and the long-term economic development strategy. All these might be easily illustrated by the example of Finland, a small but developed European country (Dahlman et al., 2006). With the outburst of the information revolution (in 1980s), Finnish society has been dynamically transformed towards an information society. Intensive investments have been made in mechanical engineering and science education, and this has been a success. The Finnish economy has undergone fundamental changes in the 1990s. There has been a revolutionary shift from capital-intensive and hierarchical sectors of the economy to the economy based on innovation and knowledge to an information society. Finland has become one of the most developed information societies in the world. It is considered that the fruitful activities and flexibility of Finnish engineering education have become one of the most important factors in making the transition of Finland to the knowledge economy. In turn, the modern Finnish economy is forming the informational focus of engineering education. It is mainly aimed at training highly qualified mechanical engineers capable of creating capital goods for the production of ICT (information and communication technologies) devices, as well as electronic engineers and software engineers for development and commercialization of ICT goods and services.

The world is entering a new age now—the age of the 4th Industrial Revolution, the age of the digital economy. Industry 4.0 will back the digital economy with the highest level of manufacturing automation, using intelligent computer machines and robots with elements of artificial intelligence (AI) capable of interacting with humans, learning and improving in production and management processes. The digital economy is able to meet the challenge of moving from mass production of standard goods and services to creating high-quality goods and services that meet individual needs and preferences. Industry 4.0 is essentially a flexible, digitally controlled programmable production that can be immediately adapted to manufacturing new products.

Hence, the new epoch makes demands on the knowledge and skills of employees in the digital age. Currently, advanced countries have not yet witnessed a true digital modernization of their education systems, despite a significant increase in training specialists in STEM areas that are most in demand in the digital economy. So, what are the key labor features for people in the age of the digital economy? Firstly, information and knowledge are becoming the main economic resources. The specificity of these resources is that they are the result of human intellectual activity. Therefore, in the age of the digital economy, it would be appropriate to speak about the strategy of intellectual capital formation (Edvinson & Malone, 1997). Human capital is defined as an employee's productive capacity. Intellectual capital is broader than the human one, and it includes creative skills and skills in using the information as a self-sustaining production factor, along with traditional factors such as labor and capital. It is the intellectual capital that will be the key determinant of efficiency in the digital economy.

Secondly, most employees in the digital economy will have to deal with maintenance and control of intelligent machines, i.e., computers, robots, and additive 3D printing devices with elements of artificial intelligence, the language of which is the language of digital technology. Therefore, they will require new skills and competencies, namely digital skills and competencies. The majority of university graduates still have a grossly inadequate level of digital skills and competencies. This also includes skills and abilities for analysis and processing of digital data and digital information, the so-called "computer analytics" of data and of "big data" in particular. Therefore, training in all traditional professions requires additional training in abilities and skills to work with digital data and digital technologies.

Thirdly, since the innovations of the Fourth Industrial Revolution predominantly emerge in the interdisciplinary field through the convergence of technologies, there is a need for dissemination of interdisciplinary education and research programs. The latter should now become the norm for most professions. The booming nanobiotechnology and genetic engineering industries are good examples of this. The ability to effectively interact with intelligent machines will be of particular importance for employees. Research shows that it is the symbiosis of a highly skilled human and a friendly intelligent robot that will be the most productive workforce in the digital economy. Moreover, a skillful and friendly partnership with intelligent machines will enable trained people to overcome their own natural limitations, both physical and mental.

Fourthly, given the exponential growth of digital technologies, which is a new phenomenon, special attention needs to be paid to the ability of employees to adapt to new working conditions constantly and to assimilate new skills and new technologies. Hence the requirement that continuous education throughout working life and adaptation to rapid technological changes become a need for every person, as they say, their "state of mind." The education system should be integrated into the consciousness of every person with a well-known folk wisdom "Live and learn" as an imperative.

The main features of the digital economy listed above lead directly to the basic requirements for the specialists of the future:

1. Deep fundamental knowledge in mathematics, information theory and natural sciences.
2. Ability to simulate complex processes on a computer and set up digital experiments using mathematical models.
3. Ability to innovate and think systemically.
4. Ability to work in an interdisciplinary team.
5. Willingness to continuous education, to periodically change the professional field.

Fundamental knowledge has always been more in demand in the periods of transition from one industrial revolution to another, from one technical and economic paradigm to another. This is the period we are going through nowadays. Most of the innovative products, including such unique ones as airliners and automobiles, are already being designed, modeled, and tested for their strength and performance entirely using software tools (3D CAD and PLM systems) on supercomputers. Interdisciplinary knowledge and skills allow an employee to acquire knowledge from different areas, combine and concentrate it for a successful solution of a specific practical problem.

Automation of production and management with intelligent machines will rapidly free people from routine mental activities and lead to a dramatic increase in the demand for highly skilled employees with digital skills and competencies. Such personnel were previously trained, so-called by a person, but now their training should be made in large numbers. Indeed, the well-known McKinsey Global Institute, based in the USA, investigated this issue and came to the conclusion that there is a rapid increase in demand for highly skilled jobs in the developed world today, requiring the use and support of computer (digital) technologies, development of mathematical models and software, and maintenance of robotics. McKinsey claims that high-tech companies around the world are experiencing a shortage of 40 million specialists with higher education in STEM fields (mathematics, programming, research, engineering, and high technology) (MGI, 2015).

In today's environment, knowledge-intensive industries represent the production base and the most important source of income for industrialized countries:

– Knowledge-intensive technologies and industries are now the main drivers of economic development, both domestically and globally; this applies to both products and services.
– Common features of knowledge-intensive industries that determine their role in the economy as a whole are growth rates two–three times higher than the growth rates in other sectors of the economy; a large share of added value in the final product; increased salary of employees; high innovation potential, serving not only this particular industry but other sectors of the economy as well, generating a "chain reaction" of innovations in the national and global economy.

Innovations in engineering and technology are currently mostly formed on an interdisciplinary basis as a result of the knowledge transfer from one area to another and their mutual influence. In the last decade, it has been common to highlight the need to develop special "competences" for the specialists, focused on the ability to apply them in practice, in real business, when creating new competitive products. As a result, a new quality of engineering education is achieved, providing a set of competencies, including fundamental and technical knowledge, the ability to analyze and solve problems using an interdisciplinary approach, and mastery of project management methods. The interdisciplinary learning approach allows one to teach students to independently "obtain" and classify knowledge from different areas, concentrate it for a specific task to be solved.

Engineering education, in particular, will play a central role in our future society based on knowledge and innovative technologies. Therefore, engineering education should be modernized, taking into account new trends in the development of society, requirements of the environment and atmosphere, as well as the strategic goals of the state. Engineers of the twenty-first century need to demonstrate good fundamental and applied scientific knowledge along with advanced general skills, such as the ability to acquire knowledge on their own, so that they could cope with a rapidly growing amount of new knowledge. The engineers of the future should be able to adapt to the changing emphasis in scientific fields such as information technology and bioengineering. It is also important to have interdisciplinary knowledge and communication skills, as well as a lifelong learning desire.

It is well known that it is not possible to provide engineering students with all the knowledge they may need in their professional practice. Professional skills often become obsolete so quickly that engineering education fails to achieve its goal if it prevents graduates from continually renewing their knowledge and skills. Teaching how to learn, and especially how to relearn, is becoming an increasingly important task. Lifelong continuous education should become a necessity for an engineer. A positive attitude towards learning and a desire to learn are key characteristics of the twenty-first century engineer, and these attitudes should be developed in engineering education. According to Rosstat, the participation of Russia's population in continuous education was 24.8% in 2008. Generally, this figure is much higher in countries with high innovation activity, i.e., it is 37.6% in the UK; 41.9% in Germany; 77.3% in Finland!

Continuity and interdisciplinarity should become important structural factors of engineering education. Interdisciplinary research helps engineers cope with the changing social, economic, and political environments that are interconnected with technology and its development. Thus, interdisciplinary research, especially in humanities and economics, should be an integral part of engineering education. The use of information and communication technologies to support the process of learning may lead to significant interdisciplinary research results.

Engineers as creators of new complex technologies cannot be narrow specialists. Multi-skilled engineers will be more and more in demand in the future. Engineers of the twenty-first century should be fluent in information and computer technologies. They need to have a deeper understanding of environmental issues, not only in terms of environmental damage already caused but also in predicting the impact of the engineering activities at present.

Engineering students prefer an active learning method. An engineering education program should include the widespread use of ICT, since it has become a widespread technology and is used in almost all sectors of the modern economy. Problem-based learning is preferable, so students should be encouraged to participate in teaching the subject. "Contextual learning," when the motivation for knowledge assimilation is achieved by building relationships between specific knowledge and its application, is one of the promising methods used in innovative engineering education. This method is quite effective, as the aspect of the application is critically important for students.

Thus, implementing new principles of education, especially in terms of engineers training, objectively will pave the way for the situation when not physical or financial capital will be the main production factor in the digital economy, but intellectual capital and human resources. It is the shortage of competent, highly qualified personnel rather than the availability of physical capital that may be a deterring constraint for the development of the digital economy. Therefore, developing and implementing a strategy for the formation of intellectual human capital for the coming digital age will be of paramount importance.

4 Technological Convergence and Job Substitution

Industrial production at the industrial stage of economic development was characterized by a gradual process of replacing living labor with materialized one. Therefore, the general trend of developing real production is to reduce labor intensity and increase products capital intensity at the same time. This process will only accelerate in the digital economy, and we will also observe a growth trend in knowledge intensity in addition. Manufacturing attracts large amounts of fixed investment when it becomes more knowledge-intensive, and, conversely, extended renewal of fixed assets is an important factor in the development of R&D. And the latter will increase the demand for research professionals. Consequently, knowledge intensity and capital intensity are interrelated processes in the course of digital transformation.

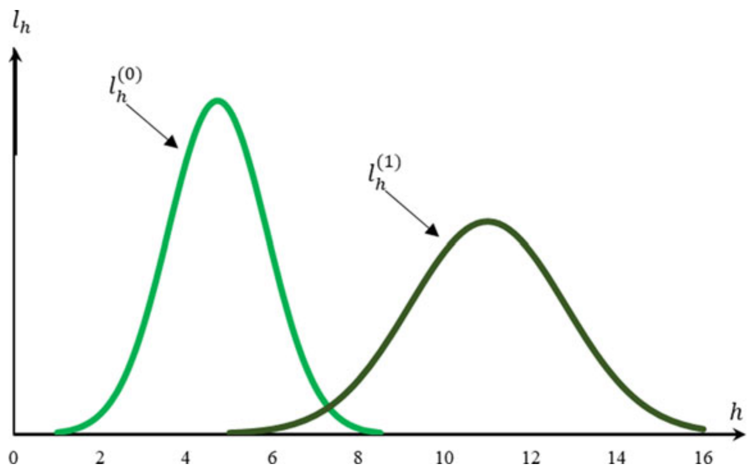

Fig. 1 Labor force supply distribution curves by skill levels in the 2020s $\left(l_h^{(0)}\right)$ and 2030s $\left(l_h^{(1)}\right)$. Source: Authors' creation

We have provided a detailed description of the mathematical models for assessing labor substitutions in the digital transformation of the economy in our earlier studies (Akaev et al., 2021). In the development of our proposed models, we obtained a more accurate assessment for the polarization of labor in the 2030s by constructing a forecast of distributing the relative labor force by skill level for the 2020s and 2030s for the American economy (Fig. 1).

We have constructed a distribution curve describing the probability of technological substitution of the labor force for the early 2030s using the predictive values of the distribution characteristics for the relative labor force by a skill level (see Fig. 2).

Model calculations have shown that the distribution of efficient labor force in the economy after the completion of digital transformation in the 2030s takes the form of a two-humped curve shown in Fig. 3.

Further, the model calculations allowed us to obtain the percentage of effective employees of low, medium, and high qualifications, which are placed in Table 1 in the "revised values" column.

As may be seen from this table, the initial assessments and revised values differ slightly from each other, which indicates the reliability of the initial assessment.

5 Conclusion

The convergence of technologies, primarily in the form of digital technologies, will permeate all spheres of society, since they are general-purpose technologies. Virtually all industries of the modern economy will see a decline in the need for human

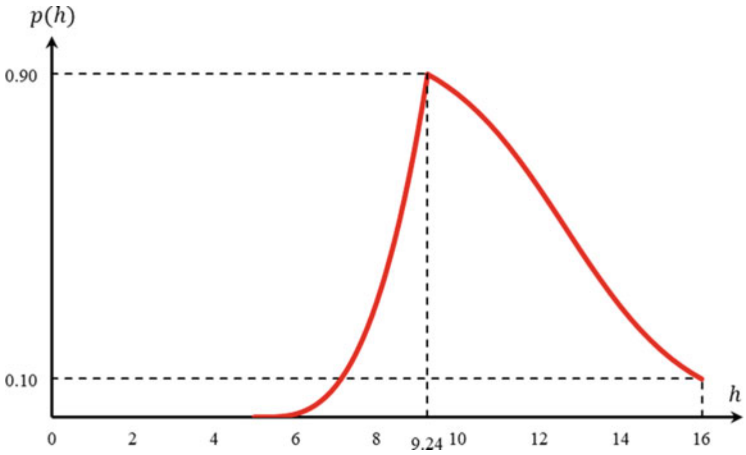

Fig. 2 Predictive curve of the probabilities for technological labor force substitution for the 2030s. Source: Authors' creation

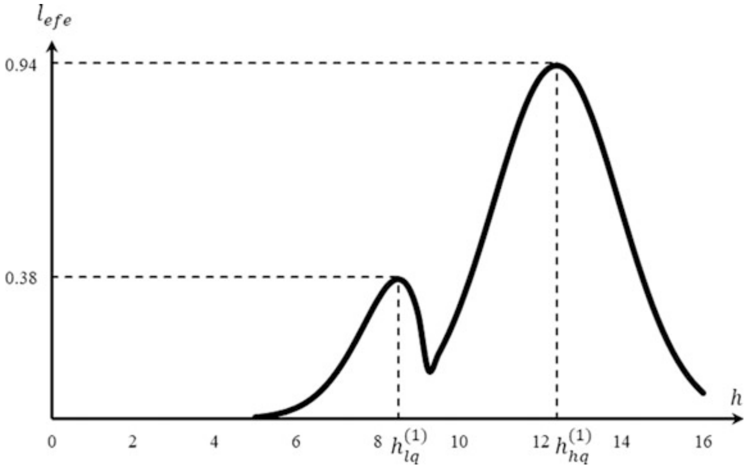

Fig. 3 Distribution curve of the efficient labor force employed in the digital economy in the 2030s. Source: Authors' creation

Table 1 Percentage of low-, medium-, and high-skilled employees before and after digital transformation (%)

Before digital transformation		$l_{ef}^{(l)} = 10.5\%$	$l_{ef}^{(m)} = 72.4\%$	$l_{ef}^{(h)} = 17.2\%$
After digital transformation	Initial assessment	$l_{efe0}^{(l)} = 14.0\%$	$l_{efe0}^{(m)} = 55.9\%$	$l_{efe0}^{(h)} = 30.1\%$
	Revised values	$l_{efe1}^{(l)} = 16.4\%$	$l_{efe1}^{(m)} = 54.3\%$	$l_{efe1}^{(h)} = 29.3\%$

labor as digital technologies is introduced into it. Moreover, it will decline really fast, since innovative technologies will be distributed over a ready-made infrastructure (namely digital information and communication networks) for the first in the entire history of the industrial age. Obviously, this infrastructure will be further developed and become more broadband and high-speed. The technologies of the 4th Industrial Revolution will cease to be a means of increasing productivity for millions of employees, as they will simply replace them in all jobs associated with routine cognitive activities. This will naturally lead to a continuous rise in technological unemployment. It might lead to a further reduction in the percentage of the economically active population, if an increase in qualifications of a certain part of employees does not keep up with the increase in the level of technology.

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