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IMPACT OF TECHNOLOGICAL PROGRESS ON EMPLOYMENT PROSPECTS AND COMPETENCE DEVELOPMENT

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Technological Development, Changes on Labor Markets, and Demand for Skills

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This special issue of the journal is dedicated to the role of skills and competencies play in coping with various challenges that labor markets face nowadays. These challenges are triggered by the current wave of technological change driven by new digital technologies, such as artificial intelligence, machine learning algorithms, cloud computing, and dexterous robotics. Although the impact of technological change on labor markets is not a new phenomenon and has been studied extensively over the past several decades, we do not know much about the effects of new digital technologies, which seem to outperform humans in many areas that have until recently been considered as "human terrain" [*Brynjolfsson, McAfee,* 2014]. These rapid developments significantly affect the demand for workers, who possess specific capabilities by changing their work content. They also create new forms of work, for instance, by enabling people to work remotely, by promoting collaboration in digital spaces, and by creating new opportunities for individual entrepreneurship and innovation activities. Thus, this special issue aims at shedding more light on different ways in which current technological progress affects the way we work while focusing on the role of skills. Moreover, it aims at better understanding the multi-dimensional nature of the impacts of the digital revolution by focusing at the level of individuals, organizations, and regions. Finally, it aims at identifying challenges for policymakers and education practitioners who aim at developing various measures to successfully cope with the challenges induced by the current technological change.

The special issue is organized as follows. The first section includes articles dedicated to new developments on the labor markets that affect individual workers, such as the effects of digitalization on occupations and demand for skills as well as the emergence of new forms of work. The papers in this section discuss worker skills that become more valuable in the light of these new trends on the labor markets. The second section of the special issue is dedicated to the regional adaptation strategies by emphasizing the role of regional knowledge and skills pool, for instance, for the emergence of start-ups in the digital sector and for managing the risks of susceptibility of regional workforce to digitalization. Last but not least, the third section deals with the educational implications of the current technological change by discussing promising educational practices aimed at developing competencies required in the 21st century.

Digitalization is undoubtedly one of the key challenges for current labor markets. The paper by Frank Fossen and Alina Sorgner entitled "Mapping the Future of Occupations: Transformative and Destructive Effects of New Digital Technologies on Jobs" opens the first section of the special issue by proposing a multi-dimensional approach to conceptualize the impact of digitalization on occupations. On the one hand, destructive digitalization substitutes human labor. On the other hand, transformative digitalization changes the content of jobs and complements human labor. It is argued in the paper that although transformative and destructive digitalization can affect occupations in distinct ways, occupations differ only *gradually* with regard to the impacts of digitalization on them. Based on representative data on occupation-specific characteristics in the U.S. (O*Net database), the authors demonstrate that a large share of occupations either face a very strong transformative and at the same time a very low destructive digitalization, or vice versa. Thus, new digital technologies have strong potential to change or to replace a vast number of occupations. The key competences will likely be the ability to cope with the

transformation of one's occupational environment and to adapt to these changes by means of acquiring capabilities that can be defined as automation bottlenecks, such as originality, social perceptiveness, negotiation, and persuasion. The study concludes with a discussion of the implications of the proposed multi-dimensional approach to conceptualize the impacts of digitalization on jobs for policymakers attempting to design programs to mitigate the destructive effects of digitalization and better exploit the opportunities that arise from its transformative impacts.

The next paper in this section was co-authored by Yaroslav Kuzminov, Pavel Sorokin, and Isak Frumin and entitled "Generic and Specific Skills as Components of Human Capital: New Challenges for Education Theory and Practice" offers an overview of the discussions concerning how the concept of human capital has evolved over the previous decades, thereby emphasizing the limitations of the traditional approach based on measuring the formal level of education in explaining, for instance, the slowdown of economic growth in several countries. The new reality of the 21st century poses a serious challenge not only to the theory of human capital, but it also calls for significant adjustments in existing educational systems and for a revision of educational policies. These should account for the rapidly changing demand in worker skills around the globe and the increasing relevance of types of human capital that go far beyond the formal education, such as creativity, critical thinking, lifelong learning, non-cognitive skills, and human agency. Particularly human agency or the ability of individuals to be self-organizing and pro-active appears to gain in importance in the coming decades not only for entrepreneurs but also for dependently employed workers.

An in-depth analysis of the digital transformation of occupations in the financial sector is provided in the paper "Twenty-First Century Skills in Finance: Prospects for a Profound Job Transformation" by Natalya Shmatko and Alina Lavrinenko. Based on a comprehensive analysis of job advertisements posted on major online recruiting platforms and expert interviews, the authors were able to determine the key competences that employers in the banking sector are looking for when recruiting employees. The demand is particularly high for advanced digital skills, including applied computer programming, Big Data analytics, and the use of specialized software. Moreover, employers are increasingly looking for universally applicable competences or "soft" skills in the potential candidates, such as strong interpersonal skills and stress tolerance. In further analysis, it is shown that although occupations in the banking sector are differently affected by digitalization, many of those occupations are facing strong transformative digitalization, which has the potential to change the spectrum of tasks human workers will perform in these occupations in the future. This development suggests that another key competence of employees in the banking sector will be the ability to deal with uncertainty and to adapt in a timely to the rapidly changing tasks in their occupations.

Technological progress is also conducive to the emergence of new forms of the organization of work. Ina Krause's paper entitled "Coworking Space: A Look into the Future of Work" deals with the question of how the organization of work has evolved over time. The author reviews the history of modern forms of work, thereby distinguishing between three major periods: Fordism (postwar industrial period), Toyotism (diversified-quality production systems), and Uberism (shared and virtual economy). Each period is characterized by distinct ways of organizing the working process, different skill requirements, and work attitudes of individuals. Earlier periods were characterized by a strong focus on production work with non-flexible working times and a high demand for manual skills (during the Fordism period) and, subsequently, project-based type of management with a strong demand for technical skills and more flexible working times (during the Toyotism period). In contrast to the earlier periods, the current Uberism period relies on cooperative management of knowledge work. It requires more "soft" skills, such as interpersonal, intercultural, and self-promotion skills, and it relies on the virtual working context as an important development that has become possible due to digital technologies. One implication of this development is that the concept of work loses its organizational and local embeddedness and it influences individuals' identities even stronger than in the former periods. This has implications with regard to the need to revise the current concept of work and to develop strategies that allow for embedding it into an appropriate institutional setting.

The second section of the special issue is dedicated to the regional adaptation strategies to challenges related to current technological change. The papers in this section investigate the role of regional knowledge and regional skill endowments that will help regions adapt to digital transformation. The paper by Michael Fritsch and Michael Wyrwich entitled "The Role of Knowledge, Skills, and Opportunities in the Emergence of Information Technology Start-ups" investigates the regional emergence of new businesses in information technologies (IT) in Germany. The share of firms in the IT sector can be expected to grow in the near future, thereby positively contributing to regional employment growth. Firms in the IT sector may also be important for the regional economy in indirect ways, for instance, by producing IT knowledge and IT skills that are likely to be in high demand in the future. The authors report strong differences in the regional distribution of start-up activities in the IT sector in Germany. The main factors for these differences are the regional employment share in IT services and the presence of higher education institutions (HEIs) with education and research in computer science. These re-

sults suggest that rural regions and regions that lack HEIs and human capital relevant to the IT sector may experience shortage of IT-start-up activity in the foreseeable future.

Another spatial aspect of the current digital transformation, namely the relationship between Industry 4.0 and clusters, is discussed in the essay "The Industry 4.0 Induced Agility and New Skills in Clusters" by Marta Götz. The author attempts to link the existing literature on clusters that does not sufficiently account for the most recent digital transformation with the well-established literature on Industry 4.0. Although the paper is of a speculative nature, it nevertheless draws attention to the potential ways in which digital transformation affects clusters and particularly firm agility by enforcing their adaptability and by developing the skills of the cluster workforce.

Stepan Zemtsov, Vera Barinova and Rosa Semenova in their paper entitled "The Risks of Digitalization and Adaptation of Regional Labor Markets in Russia" investigate the differences in the susceptibility of regions to the automation of labor in the case of Russia. The authors identify several regional factors that are favorable for successfully dealing with this challenge, among which one can mention the presence of agglomerations with a high concentration of diversified human capital, well-developed IT infrastructure, favorable regional conditions for entrepreneurial activities, and high innovation potential. Many regions facing high risk of automation currently lack these assets, which makes them more vulnerable in the long-run. The authors also formulate recommendations for regional policymakers who attempt to design regional development policies by means of digital technologies. Such policies will need to account for the specifics and variety of regional adaptation strategies.

Technological progress poses a major challenge to existing education systems, putting established education programs increasingly at risk of failing to meet labor market demand for new competencies. The third and the final section of the special issue is dedicated to the discussion of selected educational practices that might be useful for successfully coping with the changing demand for skills. Hillary Swanson and Allan Collins in their paper "Learning to Theorize in a Complex and Changing World" describe an innovative course, which was implemented at a public middle school in the U.S. with the aim of developing students' "soft" skills, such as abstract and critical thinking, by means of using methods of scientific theory building. Such skills, if successfully developed, will prepare the students to make decisions in increasingly uncertain and complex environments.

Last but not least, Dzamilya Abuzyarova and colleagues in their paper entitled "The Role of Human Capital in Science, Technology and Innovation" attempt to shed more light on the educational needs of the future workforce by analyzing the HSE alumni's evaluation of competencies acquired during their higher education. While the theoretical, "hard" skills acquired at the university are clearly the most valued in former students' evaluations, the analysis also reveals that new forms of extracurricular education, such as e-education (MOOC) and emotional intelligence development training, are becoming increasingly important, thus, indicating that life-long extracurricular learning will become crucial for acquiring the key competencies in the 21st century.

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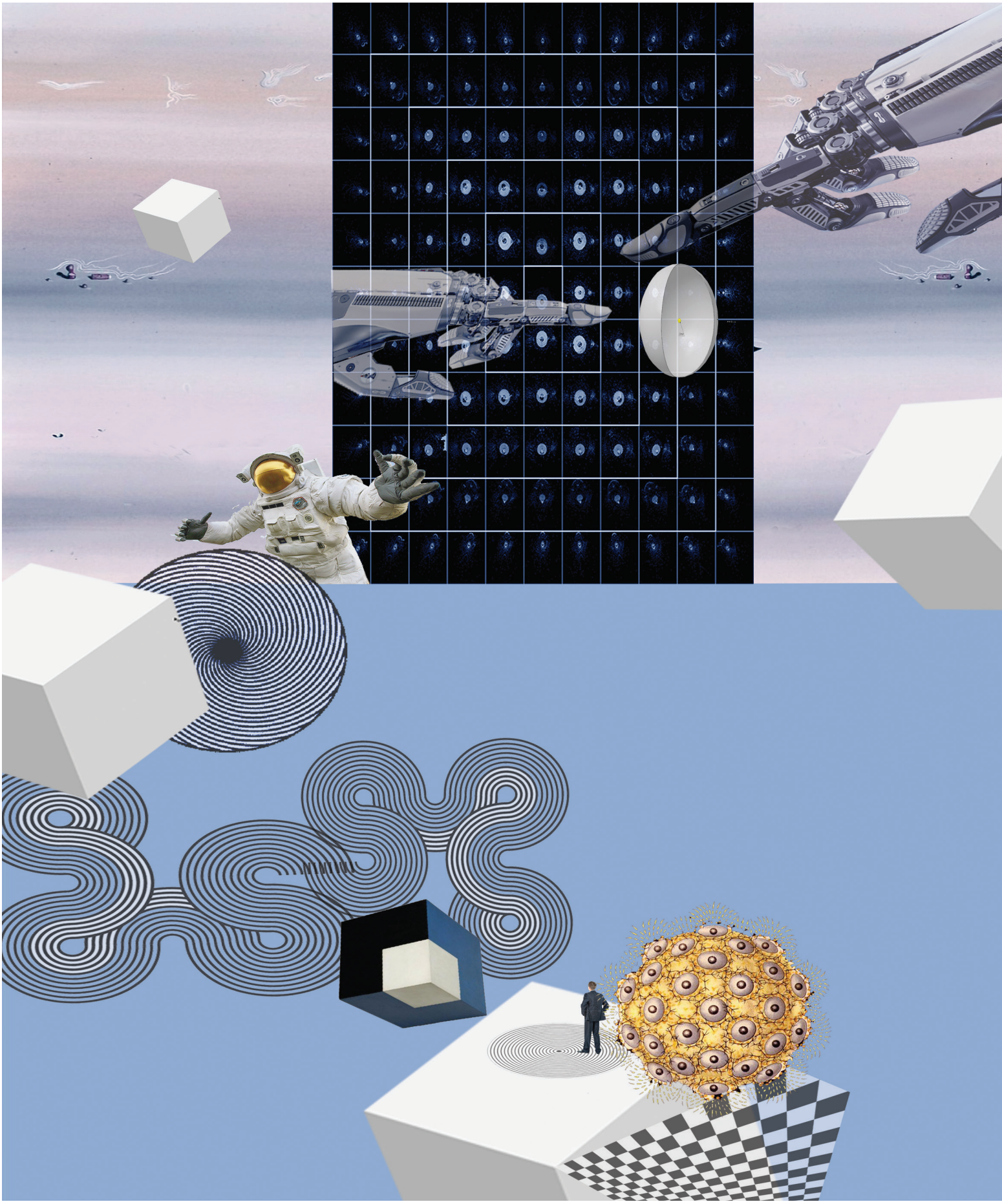
NEW TECHNOLOGIES AND FUTURE OF JOBS



Mapping the Future of Occupations: Transformative and Destructive Effects of New Digital Technologies on Jobs

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Abstract

We investigate the impact of new digital technologies upon occupations. We argue that these impacts may be both destructive and transformative. The destructive effects of digitalization substitute human labor, while transformative effects of digitalization complement it. We distinguish between four broad groups of occupations that differ with regard to the impact of digitalization upon them. "Rising star" occupations are characterized by the low destructive and high transformative effects of digitalization. In contrast, "collapsing" occupations face a high risk of destructive effects. "Human terrain" occupations have low risks of both destructive and transformative digitalization, whereas "machine terrain" occupations are affected by both types. We analyze the differences between these four occupational groups in terms of the capabilities, which can be considered bottlenecks to computerization. The results help to identify which capabilities will be in demand and to what degree workers with different abilities can expect their occupations to be transformed in the digital era.

Keywords:
digital technologies;
digitalization;
artificial intelligence;
occupations; worker skills

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As the world of labor becomes increasingly digitized, many occupations face significant changes. On the one hand, these changes induce an increasing relative demand for certain skills that cannot be performed by digital machines. Demand also increases for skills that are necessary for interacting with digital technologies. On the other, occupations that require skills that can be substituted by these digital technologies may face a high risk of becoming obsolete. This paper presents a novel approach to conceptualizing the different effects of digitalization on occupations by arguing that occupations may be affected by transformative and destructive digitalization in distinct ways. We construct a map that illustrates the different impacts of digitalization upon occupations. We also analyze the composition of capabilities necessary in occupations that are affected by different aspects of digitalization to contribute to a better understanding of the skills that make workers more competitive in the digital era.

Previous studies that investigated the effects of digitalization on occupations mostly focused on the risk of the replacement of human workers by new digital technologies, that is, the *destructive effects* of digitalization. In particular, Frey and Osborne [*Frey, Osborne,* 2017] concluded that about 47 percent of the US labor force are currently in jobs that are highly likely to be replaced by machines in the next ten to twenty years. Other studies analyzing various countries largely confirm that new digital technologies are likely to replace a substantial share of the human workforce although the average risk of automation varies a lot across countries (see, e.g., [*Arntz et al.,* 2017], for a study of OECD countries; [*Manyika et al.,* 2017; *Chang, Huynh,* 2016], for an analysis of ASEAN countries, and [*Sorgner et al.,* 2017], for an analysis of selected G20 countries).

Evidence on the *transformative effects* of digital technologies on occupations is, however, scarce. Felten et al. [*Felten et al.,* 2018] developed a measure of advances in artificial intelligence that they link to abilities and occupations. Such transformative effects suggest that an occupation will experience substantial changes, including changes in the skill requirements for individuals working in this occupation, but machines will not necessarily replace the human workers (e.g., [*Brynjolfsson et al.,* 2018]). The transformative effects of digitalization might also be related to stronger human-machine interactions (e.g., working with robots, applying AI to solve job-related tasks, etc.).

In this paper, we argue that digitalization impacts occupations in a gradual, two-dimensional way, rather than being either destructive or transformative. Indeed, the results of our empirical analysis suggest that about 75% of the employees in the United States are affected by either destructive or transformative digitalization, but not both, while the remaining 25% are affected by both digitalization types or virtually unaffected by any type of digitalization. We also analyze the differences in skill requirements between occupations differently affected by digitalization.

Transformative and Destructive Effects of Digitalization on Occupations

Previous studies have mainly focused on the destructive effects of digitalization, that is, the probability that human workers can be replaced by machines (e.g., [*Brynjolfsson, McAfee,* 2014; *Acemoglu, Restrepo,* 2019]). This literature finds that large shares of the workforce in the United States are active in occupations that either face a very high or a very low risk of destructive digitalization, while only a rather small share of workers are found in occupations that face a mid-level risk [*Frey, Osborne,* 2017].

In contrast, the transformative effects of digitalization, i.e., the extent to which digitalization will affect occupations without necessarily replacing human workers, received much less attention in the literature. Such transformative effects of digitalization may change the way people work in their occupation or occupational content, with a tendency to make human workers more productive. Usually, transformative digitalization is discussed in connection with the complementary effects of technology, that is, when there are extensive human-machine interactions [*Autor,* 2015].

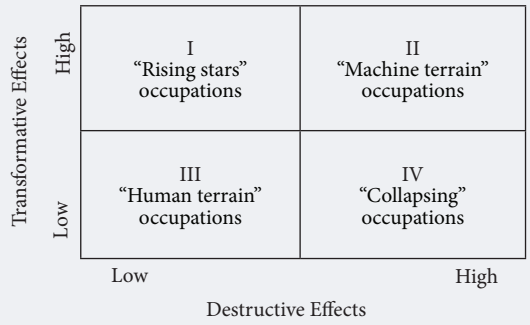
It appears that destructive and transformative digitalization has already begun to impact labor markets, but they do so in different ways. In their analysis of labor market transitions in the United States, Fossen and Sorgner [*Fossen, Sorgner,* 2019] demonstrate that destructive digitalization triggers individual transitions into unemployment and unincorporated, necessity-driven entrepreneurship, whereas transformative digitalization facilitates incorporated, opportunity-driven entrepreneurship. A study by Sorgner [*Sorgner,* 2017], which focuses on the impacts of destructive digitalization on individual labor market transitions in Germany, arrives at similar results.

It is plausible to assume that occupations are not affected by digitalization in a purely destructive or transformative way. Instead, occupations rather differ from each other *gradually* in terms of digitalization's impact on them, thus, implying that an occupation might face different levels of transformative and destructive risks at the same time.

Figure 1 demonstrates this idea visually by plotting all occupations on a two-dimensional chart where the horizontal axis represents destructive effects and the vertical axis represents the transformative effects of digitalization on occupations. In this way, all occupations can be divided into four major groups that describe the extent to which an occupation is affected by both transformative and destructive digitalization.

The group "rising stars" in Quadrant I consists of occupations upon which transformative digitalization has a high impact, but in these occupations, this

Figure 1. **Effects of Digitalization on Occupations**



Source: compiled by the authors.

does not lead to the replacement of human workers, so the risk of destructive digitalization is low. These occupations are facing significant changes in terms of work processes due to digitalization and, consequently, in terms of skill requirements. However, not all tasks performed in these occupations can be taken over by machines. Therefore, human workers are not at risk of replacement, only the division of labor between humans and machines is changing. Individuals working in these occupations will need a high level of flexibility to be able to adjust to rapid changes in their occupations. It is also likely that there is great need for acquiring further qualification in such occupations.

The group "machine terrain" in Quadrant II consists of occupations that are characterized by high transformative and destructive impacts of digitalization simultaneously, which means that these occupations are transformed due to digital technologies in ways that could make human workers obsolete. The main difference between the occupations in the group "machine terrain" and those in the group "rising stars" is that digitalization transforms the work content of the "machine terrain" occupations in a more radical way, such that there remains almost no need for human workers.

Individuals in occupations that are part of the "human terrain" group (Quadrant III) are rather unlikely to be replaced by machines (low destructive digitalization effects). At the same time, digital technologies do not exert much transformative influence on these occupations either. Thus, it can be assumed that individuals in these occupations possess skills that cannot currently be performed by machines and there is little need for human-machine interactions in such occupations. Moreover, the progress in new digital technologies designed to overcome these bottlenecks in computerization might be relatively slow. Manual, non-routine tasks, especially those that need to be performed in unstructured environments, possibly constitute a major part of the tasks in these occupations.

Finally, the "collapsing" occupations (Quadrant IV) are occupations that face a high risk of destructive digitalization, in which there will be little need for "human" skills. In the future, it will be possible to automate these occupations nearly completely without even transforming the occupations substantially. These occupations are likely to consist of manual and cognitive routine tasks. The computerization of occupational tasks is rather straightforward in "collapsing" occupations.

To summarize, the four groups of occupations can be distinguished by the level of digitalization's impact, which can be either destructive, transformative, or both. It is also very likely that the groups are different concerning the skills of individuals working in these occupations. In the following empirical sections, we categorize occupations into the groups and analyze the differences between them.

Data

Measures of the Impact of Digitalization on Occupations

To map occupations according to the impact of digitalization, we use two measures of occupational susceptibility to digitalization that we interpret as destructive and transformative impacts. To measure destructive digitalization, we use computerization risks of occupations estimated by [*Frey, Osborne,* 2017]. The measure captures the risk of the replacement of human workers by machines in the next 10-20 years based on expert judgments and selected characteristics of occupations from the O*Net database compiled by the US Department of Labor.[1] In a first step, technology experts provided their estimates for 71 occupations concerning their susceptibility to automation in the next 20 years. In a second step, this list of hand-classified occupations was used as a training dataset for a machine learning algorithm that classified the remaining occupations in the O*Net database based on the job requirements identified as computerization bottlenecks.

As in [*Fossen, Sorgner,* 2019], we use a measure of past advances in AI developed by [*Felten et al.,* 2018] as an indicator for transformative digitalization. This measure is based on the AI Progress Measurement dataset provided by the Electronic Frontier Foundation (EFF) in combination with O*Net occupational data. In contrast to the measure of destructive computerization that predicts future developments, the measure of transformative digitalization is based on past developments (2010-2015) in 16 categories of AI.[2]

[1] O*Net is a database of quantitative indicators of occupational requirements, workforce characteristics, and occupation-specific information in the United States.

[2] Categories of AI are, for example, image recognition, speech recognition, and translation, among others.

Table 1. **Computerization Bottlenecks and Corresponding Variables from O*Net**

Computerization bottleneck	O*Net variable	O*Net description
Perception and manipulation	Finger dexterity	The ability to make precisely coordinated movements of the fingers of one or both hands to grasp, manipulate, or assemble very small objects.
	Manual dexterity	The ability to quickly move your hand, your hand together with your arm, or your two hands to grasp, manipulate, or assemble objects.
	Cramped work space, awkward positions	How often does this job require working in cramped work spaces that requires getting into awkward positions?
Creative intelligence	Originality	The ability to come up with unusual or clever ideas about a given topic or situation, or to develop creative ways to solve a problem.
Social intelligence	Social perceptiveness	Being aware of others' reactions and understanding why they react as they do.
	Negotiation	Bringing others together and trying to reconcile differences.
	Persuasion	Persuading others to change their minds or behavior.
	Assisting and caring for others	Providing personal assistance, medical attention, emotional support, or other personal care to others such as coworkers, customers, or patients.

Note. This table was adopted from [Frey, Osborne, 2017]. These authors also include a variable "fine arts" as part of the bottleneck "creative intelligence". We do not use this variable in our analysis because it is coded as "irrelevant" for more than half of the occupations in O*Net.

Source: compiled by the authors..

These AI categories are linked to 52 distinct abilities that O*Net uses to describe job requirements. This way, the authors estimated progress scores in AI performance for each occupation.

Both measures of destructive and transformative digitalization are available at the 6-digit code level of the System of Occupational Classification (SOC). For 751 occupations from O*Net, we were able to merge both the measures of the computerization probability and of advances in AI.

Occupation-Specific Characteristics

Our measures of occupation-specific characteristics that we use to describe the occupations also stem from the O*Net database. We use O*Net variables corresponding to the bottlenecks to computerization, as defined by [*Frey, Osborne,* 2017]. These authors identify three broad areas of capabilities that are particularly difficult for machines: perception and manipulation, creativity, and social intelligence. Table 1 lists and describes these variables. We assume that these occupational characteristics are the most important for distinguishing between the four groups of occupations that differ with regard to the impact of digitalization, since they represent capabilities that are likely to be in high demand in the future due to their low susceptibility to digitalization.

Results

Descriptive Statistics for Digitalization Impact Measures

Descriptive statistics of both measures of digitalization are shown in Table 2. The destructive digitalization measure takes values between 0 and 1, reflecting its probabilistic nature. The transformative measure is an index that takes positive values but does not allow for straightforward interpretation. Larger values of this measure indicate more pronounced advances in AI in a particular occupation, which we interpret in terms of the stronger transformative impact of digitalization upon that occupation.

We argue that both digitalization measures capture different impacts on occupations. This is supported by Figures 2 and 3, which show the distributions of the measures of destructive and transformative digitalization, respectively. The measure of destructive digitalization, which is operationalized by the computerization probabilities, has a pronounced U-shaped distribution suggesting that a large share of all occupations face either a very high or a very low risk of destructive computerization (Figure 2). The share of occupations with middling levels of computerization risk is rather low. At the same time, our measure of transformative digitalization, which is operationalized as advances in AI, has a well-pronounced bell-shaped distribution (Figure 3). This means that a large share of all occupations face moderate levels of transformation due to digitalization, while only few occupations face a very strong risk of transformative digitalization or will remain almost unaffected. However, there are several occupations in our sample (airline pilots, air traffic controllers, surgeons, and physicians) with impact scores of transformative digitalization that are more than three standard deviations above the population mean. Indeed, these occupations face a very strong impact from transformative digitalization, but they are unlikely to disappear, since the destructive digitalization risk for these occupations is very low to moderate. Last but not least, a large negative correlation coefficient between both digitalization measures

Table 2. **Descriptive Statistics of Digitalization Measures**

Impact of digitalization:	**Destructive digitalization**	**Transformative digitalization**
Operationalization:	Computerization probabilities [*Frey, Osborne,* 2017]	Advances in AI [*Felten et al.,* 2018]
Mean	0.579	3.170
Median	0.690	3.164
Standard deviation	0.371	0.706
Minimum	0.003	1.417
Maximum	0.990	6.537
Number of observations	751	751

Note: Values reported are weighted by the employment in each occupation in the United States.

Source: compiled by the authors.

(ρ = -0.48) further reflects that our measures capture different aspects of digitalization.

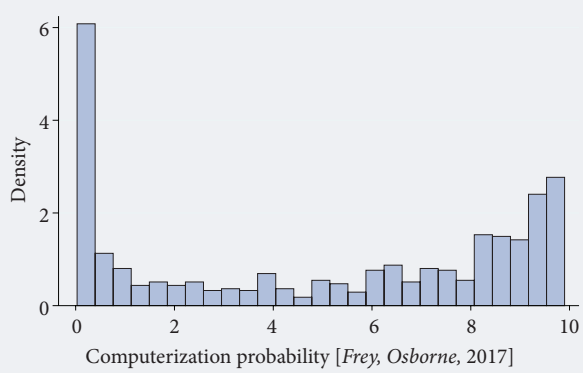
Mapping the Effects of Digitalization on Occupations

In this section, we map occupations according to the expected impact the new wave of digitalization will have upon them. We also describe the four major groups of occupations with respect to required capabilities, as outlined above.

Figure 4 shows our mapping of the occupations using the measures of destructive and transformative digitalization. We split the chart area into four quadrants at the median values of the two measures, weighted by US employment in the occupations (Table 2). The majority of occupations fall either into the group "rising stars" or "collapsing" occupations, and thus, they face either high levels of transformative digitalization or they are severely affected by destructive digitalization, but not both. This is not very surprising given the strong negative correlation between the destructive and transformative digitalization measures. This observation is also compatible with the previous literature that discusses substitutive and complementary effects of digitalization on labor markets. However, there are also many occupations on the map that are strongly affected by both digitalization types ("machine terrain" occupations) or that are not affected by digitalization in any significant way ("human terrain" occupations). This result suggests that digitalization cannot be viewed as impacting occupations in an either destructive or transformative way. Rather, digitalization should be considered as having more gradual and complex effects upon occupations. While we suggest differentiating between the two dimensions here, future research might identify even more relevant dimensions.

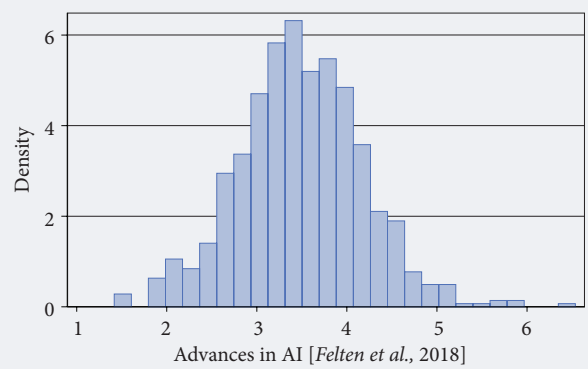
Figure 4 further illustrates the employment shares in each quadrant that are indicated by the size of the bubbles, each of which represents one of 751 occupations. Employment shares are highest in the "rising stars" group (37% of total employment in the United States) and the "collapsing" occupations group (38%), while 11% of the workforce are employed in "machine terrain" occupations and 12% in "human terrain" occupations.[3] Table 3 lists occupations with more than one million employees and those with very large or very low scores in the measure of advances in AI. These occupations are labeled in Figure 4 using the same occupation identification numbers as in the table.

Figure 2. **The Distribution of the Measure of Destructive Digitalization**



Source: compiled by the authors.

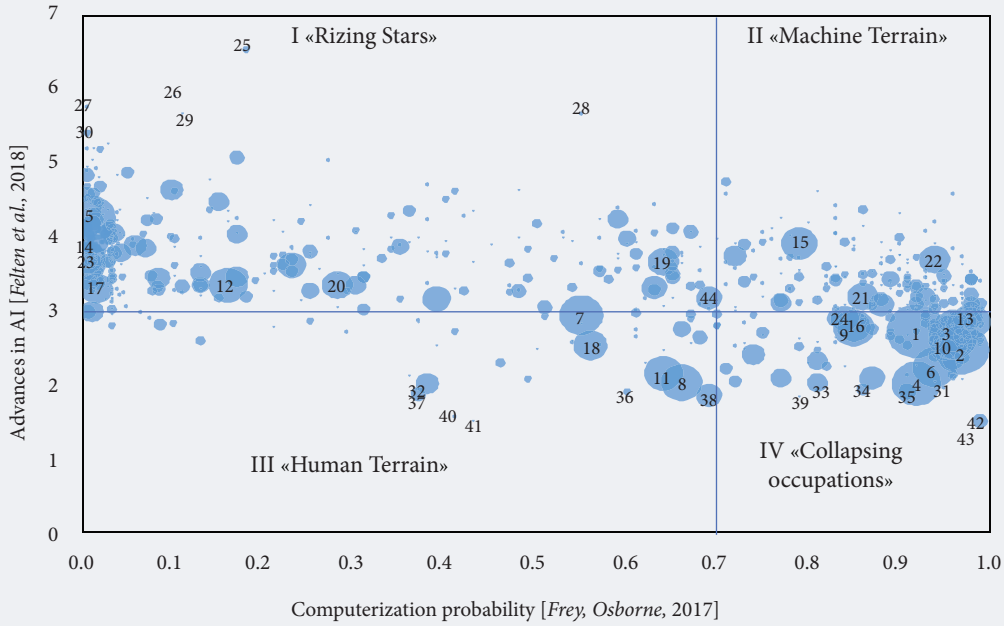
Figure 3. **The Distribution of the Measure of Transformative Digitalization**



Source: compiled by the authors.

[3] There is also a tiny share of employment (about 1%) in occupations that have the weighted median level of computerization probabilities (destructive digitalization impact), and thus, we did not assign them to any quadrant. These occupations are housekeepers and painters of transportation equipment (both between "human terrain" and "collapsing occupations"), as well as light truck or delivery services drivers (at the intersection of lines representing median values of both digitalization measures).

Figure 4. **A Map of Effects of Digitalization on Occupations**



Note. Each bubble represents one occupation. The size of the bubbles reflects total US employment in the occupations. The horizontal and vertical lines represent median values of both measures of digitalization, weighted by employment. The map shows occupational identification numbers for selected occupations: occupations with employment of more than 1 million, occupations with very large or very low scores in advances in AI, and the occupation closest to the median scores of both digitalization measures. Table 3 provides details on these occupations.

Source: compiled by the authors.

In the next step, we analyzed the characteristics of the occupations in each quadrant. Specifically, we analyzed the level of capabilities needed in the occupations that currently constitute computerization bottlenecks, and thus, cannot be performed well by machines. We use the eight occupational characteristics that have been identified as computerization bottlenecks by [*Frey, Osborne,* 2017].

Table 4 shows the average required levels of each computerization bottleneck capability for the occupations in each quadrant. Values marked in boldface represent an above-average level as compared to the full sample. This table clearly demonstrates that "rising stars" occupations require above-average levels in almost all capabilities that currently constitute automation bottlenecks, and the level of these capabilities is below average in "collapsing" occupations. The only skill, for which we find an opposite result, is manual dexterity. Manual dexterity seems to be less important for "rising star" occupations than for collapsing occupations. This is probably due to recent developments in the technologies of Industry 4.0, in particular, industrial robots that achieve high levels of manual dexterity, which are comparable to those of humans. A sample of "collapsing" occupations can be found in the manufacturing sector, such as electromechanical equipment assemblers, but also in services, such as fast food preparation workers and waiters.

Occupations in the group "machine terrain" that face high impacts of both destructive and transformative digitalization show above-average levels of such capabilities as working in a cramped workspace, manual dexterity, and finger dexterity. A typical occupation in this group is the occupation of heavy and tractor-trailer truck drivers, which demands manual skills and is performed in unstructured environments. This occupation is likely to be replaced by machines in the future, because it faces strong transformation due to AI that allows for the development of self-driving vehicles. A less typical occupation in this group is executive secretaries and executive administrative assistants, who possess many characteristics of the "rising stars" occupations, such as above-average levels of social perceptiveness, assisting and caring for others, persuasion, and originality. However, due to the very strong transformative impact of AI, in particular, in areas of voice recognition and text recognition, these occupations face the risk of replacement in the future. An example of this development is the already existing AI scheduling assistant Amy, which is able to independently schedule meetings and communicate with humans.[4] Thus, "machine terrain" occupations

[4] https://x.ai/

Table 3. **The Impact of Digitalization upon Selected Occupations**

Occ. ID (Fig. 4)	SOC code	SOC label	Advances in AI score	Computerization prob.	Total employment	Quadrant
Occupations with U.S. employment exceeding one million						
1	41-2031	Retail Salespersons	2.717	0.92	4 155 190	IV
2	41-2011	Cashiers	2.472	0.97	3 354 170	IV
3	43-9061	Office Clerks, General	2.644	0.96	2 789 590	IV
4	35-3021	Combined Food Prep. & Serving Workers, Incl. Fast Food	2.018	0.92	2 692 170	IV
5	29-1141	Registered Nurses	4.267	0.01	2 655 020	I
6	35-3031	Waiters and Waitresses	2.232	0.94	2 244 480	IV
7	43-4051	Customer Service Representatives	2.939	0.55	2 146 120	III
8	37-2011	Janitors & Cleaners, Except Maids and Housekeeping	2.031	0.66	2 058 610	III
9	53-7062	Laborers & Freight, Stock, & Material Movers	2.775	0.85	2 024 180	IV
10	43-6014	Secretaries & Admin. Assist., Except Legal, Medical, and Executive	2.580	0.96	1 841 020	IV
11	43-5081	Stock Clerks and Order Fillers	2.155	0.64	1 795 970	III
12	11-1021	General and Operations Managers	3.352	0.16	1 708 080	I
13	43-3031	Bookkeeping, Accounting, and Auditing Clerks	2.848	0.98	1 675 250	IV
14	25-2021	Elementary School Teachers, Except Special Educ.	3.734	0.00	1 485 600	I
15	53-3032	Heavy and Tractor-Trailer Truck Drivers	3.918	0.79	1 466 740	II
16	41-4012	Sales Rep., Wholesale & Manuf., Except Techn. Prod.	2.788	0.85	1 367 210	IV
17	43-1011	First-Line Supervisors of Office & Admin. Support Workers	3.307	0.01	1 359 950	I
18	25-9041	Teacher Assistants	2.539	0.56	1 249 380	III
19	49-9071	Maintenance and Repair Workers, General	3.668	0.64	1 217 820	I
20	41-1011	First-Line Supervisors of Retail Sales Workers	3.358	0.28	1 172 070	I
21	43-6011	Executive Secretaries & Executive Admin. Assistants	3.194	0.86	1 132 070	II
22	13-2011	Accountants and Auditors	3.698	0.94	1 072 490	II
23	25-2031	Secondary School Teachers, Except Special & Techn. Educ.	3.601	0.01	1 053 140	I
24	33-9032	Security Guards	2.897	0.84	1 006 880	IV
Occupations with highest scores in advances in AI						
25	53-2011	Airline Pilots, Copilots, and Flight Engineers	6.537	0.18	68 580	I
26	19-2012	Physicists	5.907	0.10	16 860	I
27	29-1067	Surgeons	5.780	0.00	43 230	I
28	53-2012	Commercial Pilots	5.682	0.55	29 900	I
29	53-2021	Air Traffic Controllers	5.680	0.11	23 970	I
30	29-1021	Dentists, General	5.414	0.00	87 700	I
Occupations with lowest scores in advances in AI						
31	39-5092	Manicurists and Pedicurists	1.972	0.95	51 990	IV
32	39-4021	Funeral Attendants	1.953	0.37	29 810	III
33	51-6021	Pressers, Textile, Garment, and Related Materials	1.942	0.81	56 600	IV
34	35-3041	Food Servers, Nonrestaurant	1.939	0.86	205 330	IV
35	35-9011	Dining Room Attendants & Bartender Helpers	1.896	0.91	390 920	IV
36	51-3023	Slaughterers and Meat Packers	1.896	0.60	88 500	III
37	53-7061	Cleaners of Vehicles and Equipment	1.864	0.37	288 110	III
38	37-2012	Maids and Housekeeping Cleaners	1.849	0.69	865 960	-
39	39-5093	Shampooers	1.839	0.79	14 220	IV
40	45-2041	Graders and Sorters, Agricultural Products	1.572	0.41	38 950	III
41	39-3093	Locker Room, Coatroom & Dressing Room Attendants	1.515	0.43	17 280	III
42	41-9041	Telemarketers	1.510	0.99	288 760	IV
43	41-9012	Models	1.417	0.98	1020	IV
Occupation with median score in advances in AI and computerization risk						
44	53-3033	Light Truck or Delivery Services Drivers	3.173	0.69	780 260	-

Notes. The 1st quadrant contains "rising stars" occupations; the 2nd quadrant contains "machine terrain" occupations; the 3rd quadrant contains "human terrain occupations", and the 4th quadrant contains "collapsing" occupations. The advances in AI are adopted from [*Felten et al.*, 2018] and the computerization probabilities from [*Frey, Osborne*, 2017].

Source: compiled by the authors.

Table 4. **Digitalization Impacts and Computerization Bottlenecks of Occupations by Quadrants**

Occupational group	"Rising stars"	"Machine terrain"	"Human terrain"	"Collapsing occupations"	Total
Quadrant	Q1	Q2	Q3	Q4	
Digitalization measures					
Advances in AI [*Felten et al.*, 2018]	**3.817**	**3.562**	2.581	2.61	3.17
Computerization prob. [*Frey, Osborne*, 2017]	0.186	**0.865**	0.477	**0.916**	0.579
Computerization bottlenecks					
Finger Dexterity	**35.959**	**40.280**	33.002	34.157	35.359
Manual Dexterity	23.013	**35.913**	25.143	**30.744**	27.832
Cramped Work Space	**22.580**	**33.128**	**22.882**	17.883	22.172
Originality	**47.134**	34.973	32.516	30.634	37.501
Social Perceptiveness	**51.154**	38.138	40.148	37.994	43.163
Negotiation	**43.228**	32.274	31.706	32.369	36.281
Persuasion	**46.133**	34.616	35.193	34.408	38.88
Assist. & caring for others	**49.183**	38.703	**46.508**	37.087	42.972
US employment	44 948 480	13 736 680	14 150 910	46 584 950	121 110 540
Share of US employment (%)	37	11	12	38	100.00

Note: The table reports on the mean characteristics of occupations weighted by US employment in the occupations. The shares of the occupations in the four quadrants do not add up to 100% because occupations that lie exactly on the split lines are not assigned to any quadrant. Boldface values are above the weighted average values for the total sample.

Source: compiled by the authors.

are different from "collapsing" occupations in that these occupations more strongly rely on non-routine manual and cognitive skills while their content faces strong transformation. For example, secretaries and administrative assistants below the executive level can be replaced by machines with less transformation of the tasks and therefore belong to the "collapsing" group. Moreover, "machine terrain" occupations are different from the "rising star" occupations in that they more strongly rely on (non-routine) skills that can be performed by new digital technologies thus making human workers in them increasingly redundant.

Last but not least, the "human terrain" occupations require above-average capability levels of "assisting and caring for others" and working in a "cramped workspace", while they have below-average levels for other computerization bottlenecks. Sample occupations in this group are, for instance, teacher assistants, customer service representatives, and funeral attendants, among others. Both digitalization impacts, transformative and destructive, are relatively low in these occupations.

In sum, the capabilities representing computerization bottlenecks are prevalent in the "rising star" occupations, whereas they are relatively unimportant in the "collapsing" occupations. "Machine terrain" occupations seem to rely more strongly on non-routine manual skills, such as manual and finger dexterity, which can potentially be automated in the future through significant transformations, while the automation bottleneck of "assisting and caring for others" requires human workers in "human terrain" occupations in the foreseeable future.

Conclusions

This paper conceptualizes the effects of the new wave of digitalization on occupations by proposing a map of occupations that differ from each other in terms of the impact level of destructive and transformative digitalization. While transformative digitalization changes the content of occupations without necessarily replacing human workers, destructive digitalization may make human workers obsolete, without necessarily transforming occupations. Mapping occupations in this way allows us to distinguish between four major groups of occupations, which we entitled "rising stars", "machine terrain", "human terrain", and "collapsing" occupations.

This distinction proves to be meaningful in the empirical analysis, which reveals that a substantial share of occupations that employ about 75% of the US workforce face either a high transformative, but low destructive impact of digitalization, or vice versa (each group accounts for about 37-38% of total employment in the United States). A key difference between "rising stars" and "collapsing" occupations is that the former require higher levels of creative and social intelligence. Therefore, human workers cannot be replaced in these occupations in the near future and will work together with new AI technologies in transformed occupations, in contrast to the "collapsing" occupations, which require fewer of these skills and can therefore be more easily replaced by machines. Workers in the "rising stars" occupations will have to cope with substantial changes in their occupations, probably by means of acquiring further qualifications in order to remain competitive, even if the risk of replacement by machines is relatively low.

Workers in "collapsing" occupations may need re-qualification to avoid potential unemployment.

Another substantial part of occupations, employing about 11% of workers, are confronted with the significant transformation of their occupational content due to AI, which puts these workers at risk of becoming redundant. Many of these occupations are characterized by relatively high levels of manual skills. Although workers in "machine terrain" occupations might also need to obtain further qualification to face the transformative changes in their current occupations, in the long run these workers might need to re-qualify themselves, since the risk of replacement is high.

Last but not least, about 12% of workers are employed in "human terrain" occupations that remain largely unaffected by digitalization. Their workplaces appear to be rather secure from the destructive effects of digitalization, but they do not seem to benefit directly from transformative digitalization that makes human workers more productive in their jobs. One of the key capabilities in these jobs is assisting and caring for others.

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Generic and Specific Skills as Components of Human Capital: New Challenges for Education Theory and Practice

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Abstract

Human capital theory in recent decades has become the basis for educational policy in many developed countries. Expert discussions, however, often undervalue research findings and developments related to this theory that since the 1970s have consistently enriched understanding of how human capital contributes to personal well-being and socioeconomic development of society as a whole. Educational policy lags behind these elaborations, which leads to a decline in the impact of education upon development worldwide. In the 21st century, fundamentally new trends in socioeconomic dynamics pose unprecedented challenges for educational systems around the world, including Russia. Despite the quantitative growth of money and time spent on education, performance per unit of education costs has fallen. The human potential, created by education, is facing more and more difficulties in its capitalization: economic growth is slowing down at both at the country level and globally. This situation brings to life new attempts to claim insignificance of education for economic growth and for individual success. So far, these attempts have not been very influential in educational policy, but in many countries, such arguments already serve as a backdrop for budget decisions that are detrimental for education. Educational systems need to complement practices that contribute to the development of human capital. In this regard, several theoretical elaborations that have not yet became part of the mainstream discussion on human capital, could be helpful for understanding the role of human capital in socioeconomic progress and possible ways to improve it in the short and long term.

Keywords: human capital; hard skills; soft skills; generic skills; labor markets; demand for skills; educational policy; entrepreneurship

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Linking Education and Socioeconomic Development through the Prism of Human Capital: a Historical Survey

Today, most scholars and experts agree that it is the human being — rather than natural resources or physical and financial capital—that drives socioeconomic development. Human capital is comprised of knowledge, skills, and practices that allow human beings to create income and other useful benefits for themselves, their employer, and society as a whole (above initial investment and operating expenses) [*Kuzminov, Frumin,* 2018]. This definition aligns with that of other sources [OECD, 2001; *Tan,* 2014; *Becker,* 1962; *Kapeliushnikov,* 2012; *Anikin,* 2017; etc.] in applying the concept of capital to the human being not in a metaphorical way, but rather as a direct and methodologically sound use of this economics term. That is, the human being is viewed as an asset that creates economic utility exceeding the expenses needed to develop and maintain it.

A two-level analytical framework of individual and aggregate data is most commonly used in academic discourse to analyze economic behavior. In contrast, our definition emphasizes three levels of investment and return vis-a-vis human capital: individual, corporate, and societal. While human capital is inseparable from its dependence on the individual student or worker, no matter who the investor happens to be, the effects of human capital and the products of labor can be subject to many possible forms of appropriation. These forms, which we may call institutions, can lead either to a relatively balanced distribution or to significant imbalances. For example, an imbalance in favor of corporations occurred in the early period of industrialization [*Rosenberg, Birdzell,* 1986; *Didenko,* 2015] and an imbalance in favor of the individual may be seen on the labor market for highly qualified IT specialists today.

The problem of human capital gives rise to a tension between classic theoretical models [*Blaug,* 1992] and socioeconomic reality, and it is this tension that some critics of the concept use in their arguments against it (*Tan,* 2014; *Klees,* 2016]. However, economic descriptions of the world often pay insufficient attention to corporations as intermediaries between the individual and society. Institutionalists, both within economics [*North,* 1990] and from sociology [*Meyer,* 2010], have been attempting to fill this gap. We focus on all three levels on which we can observe the returns on human capital.

No matter the scale or point of view of observation, the logic of investment is always present at the core of "human capital" as a concept. As we begin to analyze how this theory has developed and the ways in which it has been applied, it will be useful to start with a short historical account of the evolution of investment in human capital. We will look at various factors involved in this process, and its effects. In contrast to previous surveys [*Anikin,* 2017; *Sweetland,* 1996; *Goldin,* 2016], we shift our focus away from theoretical models of technological development in the eighteenth to twentieth centuries. Instead, we analyze investment, the resulting growth in the reach of education, and the economic outcomes. We limit our study to education, which we see as the key form of investment in human capital, but we recognize the importance of others such as healthcare and culture.

A Historical Overview of Investment in Education: Towards a Theory of Human Capital

Over the past 150 years, governments and their budgets, rather than private companies or individuals, have taken the lead role as investors in human capital around the world, including investment in education [*Tanzi, Schuknecht,* 2000]. In 1776, Adam Smith proposed the concept of "public goods," which he defined as goods that are highly valuable to society but are so expensive to produce that any individual or private group would lose money on them. Smith cites education as one of the obvious examples of this [*Smith,* 1937, p. 681].

In highly developed countries, large scale education has been seen as a necessity for progress since at least the middle of the eighteenth century, with progress generally understood as the socioeconomic and political development of nation-states [*Soysal, Strang,* 1989; *Meyer et al.,* 1992]. The first decrees on mandatory primary schooling for certain segments of the population in Prussia and Austria emerged in the second half of the eighteenth century, and the Danish state-run primary education system was created in 1721 [*Zinikina et al.,* 2016]. Rapidly growing systems of this type in North America, Australia, and New Zealand reached 86% of children by 1900, while 67% of children in Northern Europe, 29% in Eastern Europe, and 33% of children worldwide received primary education in that year [*Benavot, Riddle,* 1988, p. 202].

The growth of the education system was among the leading ideas of the time. Émile Durkheim saw education as a guarantor of social solidarity in a time of deeply divided labor [*Durkheim,* 2006]. Max Weber viewed education as a prerequisite for forming a society of the modern, rational type [*Myers,* 2004]. John Stuart Mill recognized that formal education was the only way to foster an enlightened society capable of effectively operating democratic institutions [*Macleod,* 2016]. Alfred Marshall, one of the founders of modern economics, criticized his predecessors for failing to pay enough attention to the person as a key element of the means of production, like any other form of capital [*Marshall,* 1890, p. 295].

The growth of education systems reached its zenith in the twentieth century. In 1870 there was not a single major developed country with a budget for education that represented more than 1.5% of GDP,

with 0.1% in Great Britain, 0.3% in France, and 1.3% in Germany [*Roser, Ortiz-Ospina,* 2019a]. By 1950, most of them had surpassed 2%. In 2017 the average EU government spent 5% of GDP on education, while Russia now spends 3.6% [*Kuzminov, Frumin,* 2018].

Investment in education has led to an increase in the literacy rate worldwide from 20% in 1880 to 85% in 2014. The average number of years of schooling in developed countries has gone from less than three to more than ten during the same period [*Roser, Ortiz-Ospina,* 2019b].

Public spending on formal education in developed countries has been growing especially rapidly since the 1960s, up from 2-3% of GDP in 1960 to 4-5% in 1980 [*Roser, Ortiz-Ospina,* 2019b], along with the share of GDP (5.2% of GDP growth in high-income countries in 1964 to 5.4% in 1973). Comparable rates of growth are observed in middle-income countries as well [World Bank, 2019].

Before the Second World War, the majority of developed countries provided for the spread of primary and secondary schooling [*Meyer et al.,* 1992]. Starting with the 1960s, however, there was an unprecedented expansion of higher education systems [*Cantwell et al.,* 2018]. In 1940 only 20 out of every 10,000 people on the planet were university students, but by 1960 the number was close to 40. By the year 2000, it was more than 160 [*Schofer, Meyer,* 2005].

In the early 1960s, Gary Becker [*Becker,* 1962], Theodore Schultz [*Schultz,* 1960, 1961], Jacob Mincer [*Mincer,* 1962], and Edward Denison [*Denison,* 1962], laid the groundwork for the theory of human capital. Their work coalesced into an empirically founded and complete conceptual model. By showing the mechanisms by which investment in education leads to economic growth, the model became the basis for new policies of increasing investment in education around the world.

There were, however, other reasons to invest in education. Among them were the need to foster civic literacy among the population as a means of stabilizing the political system, the desire to support social mobility, the project of building a nation state, and the social necessity of caring for children and youth [*Kuzminov, Frumin,* 2018; *Meyer et al.,* 1992; *Carnoy et al.,* 2013]. It is impossible to account for the massive boom in the scope of education (including post-secondary) over the past centuries without factoring in all these elements. Our analysis takes education's role in economic development as the primary reason for investing in it. In the case of contemporary Russia, we observe this playing out in a situation of relatively scarce economic resources [*Kuzminov, Frumin,* 2018].

In the third quarter of the twentieth century, rapid GDP growth and the expansion of education systems created a unique moment in history in which society was not only becoming convinced of the "economic benefits of education," but also had the wealth at its disposal for new investments in this sphere. Of course, the GDP growth of the 1960s that created this unprecedented economic surplus was produced by cohorts of previous generations' education system [*Marginson,* 2017; *Manyika et al.,* 2015].

According to McKinsey, most countries in the Organization for Economic Cooperation and Development (OECD) doubled or tripled expenditures on education in real prices between 1970 and 1994 [*Barber et al.,* 2011, p. 20]. Despite this, educational outcomes by OECD metrics failed to grow or diminished [*Barber et al.,* 2011]. It turned out that low outcomes in education could be observed even in countries where the financing of education had increased significantly. The trend continued, however, as average spending per student in OECD countries went up 34% between 2000 and 2008 [*Jensen,* 2012].

There have been many examples demonstrating that active investment in education systems is far from being a guarantee that a country will achieve stable economic growth [*Klees,* 2016; *Tan,* 2014]. This has caused many to doubt the importance of education as a driver of economic growth. More and more economists have returned to ideas from the 1970s about the leading role of institutions for which a good education system — as well as economic growth — are outcomes of their work rather than key inputs [*Acemoglu et al.,* 2014].

The concept of a "middle income trap" has been used to characterize the situation in which a country has used up all of its possibilities for growth, i.e., mass industrialization and investment brought about by the availability of cheap labor with the minimum required level of education, and now finds itself unable to compete with more developed countries in high-tech sectors which provide a higher level of income. According to the World Bank, only 13 of 101 countries listed as "middle income" in 1960 were able to move into the "high income" bracket by 2008 [*Agenor et al.,* 2012].

The "micro/macro paradox" [*Pritchett,* 2001] stimulated discussions on the role of education in economic growth. It describes a situation of lower macroeconomic outcomes for a country as a whole, while at the same time there is an increase in the rate of education and in the results of education at an individual level. Peru, Jordan, Mexico, and Venezuela all saw growth in the education level of the population and even an increase in the premium paid for highly educated labor, while simultaneously experiencing a slowdown of economic growth or even negative macroeconomic trends, including decreased productivity [*Tan,* 2014]. This was partially explained by the idea that new graduates were favoring jobs based on effectively extracting rent from existing assets over those that produced new value, i.e. becoming lawyers rather than engineers. New data

from China shows that the global economy's biggest engine of growth is now facing the same problem [*Yao,* 2019].

Today, Russia is facing a similar problem, which can be defined as "undercapitalized human potential" [*Kuzminov, Frumin,* 2018]. The relative value of a higher education for an individual is greater in Russia than in many highly developed countries, with about a 60% premium in wages [*Kuzminov, Frumin,* 2018, p. 97], as compared to 20% in Sweden, 56% in Great Britain, and 56% in countries that are both in the EU and the OECD.[1] According to the World Economic Forum (WEF), Russia is also among the top five countries in the world by formal education rates. However, the country is in 42nd place by the metric of "Know-How" (relating to effective labor practices in the workplace) and 89th in "Availability of Skilled Employees" [WEF, 2017].

Therefore, Russia is among the dozens of countries that fall victim to the middle-income trap, in which the growth of the education system does not result in the expected growth of productivity.

The global economic crisis further damaged governments' ability to invest in education and did nothing to increase the rate of return. According to World Bank data on the impact of education on salaries, derived using the Mincer earnings function, this correlation has remained stable throughout recent decades [*Psacharopoulos, Patrinos,* 2018]. In this climate, critics of human capital theory became more vocal, attempts were made to label it as ignoring structural and institutional problems in the economy, and there were calls to discredit it completely [*Klees,* 2016; *Tan,* 2014].

One of the most evident and fundamental problems of contemporary education is the increase in costs. On average, the cost of college in the US rose more than 170% from 1997 to 2017, while costs for the nation's education system rose 150% [*Ritchie, Roser,* 2019]. No other sector of the country's economy saw such increases in the cost of products or services. Even in healthcare, costs went up only about 100% in the same time period [*Ritchie, Roser,* 2019]. In the education sector, this phenomenon points to low productivity growth [*Baumol,* 2012] and a major crisis in the efficiency of the nation's economy as a whole. Ironically, the education system is seen as a driver of labor productivity, based on data gathered in the USA during the first two-thirds of the twentieth century.

Discussions of the link between education and economic growth often miss out on the fact that education systems in most of the world, including Russia, developed in ways that diverged from classical human capital theory. Already in the 1980s, an emphasis was made not only on formal characteristics, such as the number of years of schooling, but also on a variety of content-based characteristics, for example the capacity for non-routine action.

The move from theory to practice in developing human capital often runs into difficulties verifying conceptual models. In comparative studies between national datasets, a narrow methodology became widespread wherein the dependent variable is the rate of return of education as the individual level, and the independent variable is the number of years of schooling [*Psacharopoulos, Patrinos,* 2018]. The clear advantage of this approach is that it makes it possible to expand the set of countries in the analysis, since data about years of schooling and wages tends to be most widely available. However, its disadvantage lies in the inability to shift towards other, more precise methodologies for assessing human capital and its macroeconomic effects, including GDP data. It was precisely the impact of education on the economy, measured by GDP, that took center stage when the theory was being formulated. In the 1960s, Edward Denison showed that education is responsible for more than 70% of US GDP [*Denison,* 1962, 1966]. Most subsequent studies chose to focus on measuring returns on education at an individual level, based on various factors including years of schooling, the formal level of education, test results, and so on [*Tan*, 2014; *Klees*, 2016]. Nevertheless, the effects of education on total productivity remains a subject of interest today [*Lange, Topel,* 2006]. Human capital is an important element in Paul Romer's "endogenous growth" model [*Romer,* 1990a, 1990b].

It must be noted that the studies done by leading research centers using the narrow methodology for assessing the role of education in the economy using data about the reach of different levels of schooling by no means exclude the possibility of looking at qualitative indicators such as the cognitive and non-cognitive skills of the population [*Lange et al.,* 2018]. However, the tendency both in Russia and internationally has been to give insufficient attention to these aspects. The quality of education, even at the post-secondary level, often continues to be assessed in terms of reach, while effects are measured largely at the individual level. On one hand, there is potential here for valuable findings. For example, through a meta-analysis of hundreds of individual studies, experts at the World Bank [*Psacharopoulos, Patrinos,* 2018] found that individual return on investment in education has not fallen over the last few decades, and hovers at about 9% per year of schooling. This number represents an average of all countries analyzed across all levels of education over the past fifty years. On the other hand, however, a number of substantial questions remain beyond the scope

[1] See: https://stats.oecd.org/Index.aspx?DataSetCode=EAG_EARNINGS, viewed 25.05.2019.

of this research. We would like to determine which elements of human capital, and by what mechanism, create prosperity at the levels of the individual, the corporation, and the nation.

We suggest that discussions about education policy should be based on a more multidimensional view of human capital.

First, there must be a full accounting of the elements of human capital that have emerged in the scientific literature of the previous decades as key factors for determining the condition of the education system. These include cognitive skills, which are measured in PISA (Programme for International Student Assessment) [*Hanushek, Woessmann,* 2010], generic skills, which were recognized as significant at the end of the twentieth century [*Levy, Murnane,* 2004], and noncognitive skills [*Kautz et al.,* 2014], which have been shown by dozens of studies to have an impact on individual success. Attempts to study human capital comprehensively are being undertaken in Russia, but generally exist outside of direct engagement with government policy [*Gimpelson,* 2018]. Unfortunately, policy debates are often limited to ritualistic invocations of PISA and demonstrate a lack of understanding of some of the deep contradictions involved in such a discussion. For example, the traditional forms of instruction at Russian schools, with an emphasis on memorization or mastery of theoretical models without full-fledged practical application, do not map well to the methods of the OECD and PISA, which focus on the practical application of knowledge and fostering student motivation.

Second, more attention must be paid to socioeconomic changes, partially brought about by technological progress, that put into play components of human capital previously left behind on the periphery of the scientific mainstream. Certain characteristics of workers gain new importance in a modern economy in which both the structure and the relations between the individual, the workplace, technology, and employers are rapidly transforming. Among such characteristics may be the "capacity to adapt in a situation of uncertainty," which was proposed by Schultz way back in 1975 [*Schultz,* 1975] but still has not found its place in debates about education.

Shifts in the Understanding of Human Capital during the Second Half of the Twentieth Century and the Beginning of the Twenty-First

Gary Becker, Theodore Schultz, and Edward Denison showed that by combining physical capital and the quantity of labor with an indicator of human capital representing the quality of labor, the resulting model accurately describes the growth of the US economy and some other developed countries in the middle of the twentieth century [*Becker,* 2009]. It is important to note that during the 1950s, when the founders of human capital theory were gathering their data, the best information available to them was related to the reach of education. Objective, standardized studies of educational outcomes as a metric for the quality of education were not widely recognized at the time, neither at the national nor international levels. The first nationally representative tests appeared only in 1963, and their sample was extremely limited [*Kamens,* 2015, p. 421].

The authors of human capital theory accepted a formally fixed level of education as equivalent to the actual body of economically useful knowledge and skills. This included skills like basic literacy and arithmetic, the majority of which, when taught in the education system, increased individual productivity across the entire workforce. This component was called "general human capital." "Specific human capital," on the other hand, includes skills required for specific jobs and taught in specialized educational settings, not only in formal instruction but also acquired on the job and learned through years of experience. The Mincer earnings function, in which salary is a function of education and work experience, has become the main instrument for assessing the effectiveness of investments in human capital. It is important to note that this function gives greater weight to specific human capital as compared to the general: the log of salary equals the sum of the linear function of years of schooling and the square function of work experience [*Mincer*, 1974; *Psacharopoulos, Patrinos,* 2018].

Up until about the 1990s, governments developed their education policies based on the theory of human capital, aiming for the growth of formal indicators. A parallel line of discussion existed, trying to work out metrics for the types of human capital that would meet specific needs in the economy. Mark Blaug, for example, posed a question about which specific mechanisms and elements of human capital were responsible for creating the empirically proven link between education and individual income [*Blaug,* 1972]. Was it specialized skills learned through education? Perhaps there were innate psychological traits which the system selected for? Or was it membership in a given social class that gave students greater chances for success during their years of schooling and in their career? Blaug posited that there was a situation of internal competition among various mechanisms of development within the system of education and the labor market. In such a situation, he saw all three answers as valid and non-contradictory. Even if the labor market gives preference to people from affluent families and those who possess special talents, the education system retains its key role both as a mechanism of selection and as a contributor of useful skills that raise a student's human capital.

By directly connecting education with the labor market, the theory of human capital began, in the 1970s, to revive the issue of "employability," which was first discussed in the beginning of the twentieth century [*Guilbert et al.,* 2016; *Gazier,* 1998]. In this early moment, researchers and administrators were most interested in the cumulative impact of education upon employment. Employability was understood as the congruity between the characteristics of graduates and specific needs of the labor market and was not problematized from other points of view [*Kroll,* 1976]. In recent years, however, some researchers directly raised the question of the need to treat employability as a separate skill or set of skills which school programs should be asked to teach, and which cannot be subsumed in other subjects [*Yorke, Knight,* 2005; *Guilbert et al.,* 2016].

Despite the criticisms directed towards human capital theory, empirical studies in both developed [*Goolsbee et al.,* 2019] and developing [*Yao,* 2019] countries confirm the underlying hypothesis about the positive effects of formal education on the opportunities of a given individual on the labor market, from the point of view of employment guarantees as well as salary.

Under such conditions, it makes sense to have increasing the reach of education as a major goal, especially tertiary education. According to the British Council [British Council, 2012], the growth of this segment in the current decade has averaged 1.4% annually, which means that the college and university student population has been growing by about 21 million per year. On average, an extra year of schooling provides a greater individual benefit than other forms of investment, such as stocks or real estate [*Psacharopoulos, Patrinos*, 2018]. For critics, however, the slowdown in global growth as well as in most national economies remains the largest contradiction of human capital theory, given the high performance of data about the return on education at the individual level [*Klees,* 2016].

Mapping Education onto the Labor Market: from Skills to Jobs

A common explanation for the low rate of impact of formal education upon economic growth is a disbalance or "mismatch" between education and the labor market. This is cited both in Russia [*Roshin, Rudakov,* 2015] and internationally [*Caroleo, Pastore,* 2017].

Statistics show that more than 20% of Russian students enter college to study some form of engineering and this segment has been growing since 2014 [*Kliachko,* 2017]. At the same time, the labor market does not support a corresponding number of jobs that would make use of these engineering skills — assuming that all engineering graduates do possess such skills [*Gimpelson,* 2016]. Furthermore, in a situation of slow economic growth, the automatization of production in high tech sectors of the Russian economy leads to significant drawdowns in the number of employees. This decrease has been as much as 20% in certain sectors between 2005 and 2016 [*Gimpelson,* 2016]. As a result, engineering graduates are often forced to work as drivers, salespeople, or even security guards. The rate of employment in the retail sector rose 2.4-fold in the same period [*Gimpelson,* 2016].

Ultimately, educating engineers on a mass scale ends up being a poor use of time for the majority of students and a waste of money on the part of the state. The system for training a highly qualified workforce is fundamentally disbalanced vis-a-vis the labor market and the needs of employers. This is true even in the rare cases when the needs of employers are clearly formulated. In the high-performance manufacturing segment, there continues to be a workforce deficit, including engineers. This was laid out in the WEF report, where Russia ranked 89th in the availability of highly qualified workers [WEF, 2017].

However, the mismatch applies not only to jobs available on the labor market and specific professions associated with them, but also to skills that are in demand more broadly [*McGuinness et al.,* 2018]. This means that the problem lies not only in the sphere of specific human capital, but also in the general sets of skills that are applicable to different jobs and even to various industries. In the global context, systems of higher education feel just as much pressure to confront the mismatch in skills as they do the mismatch in professions. A wide-ranging study of the US labor market showed that employers were less likely to face a deficit of specialized hard skills than they were of soft skills, such as general attitude, the ability to take on responsibility, and so on. [*Handel,* 2003]. Another study showed that changes in the demand for widely applicable skills on the US labor market since the turn of the twenty-first century are partially responsible for the decrease in upward mobility among workers with a higher education [*Beaudry et al.,* 2016]. Conclusions such as these contradict traditional understandings about the primacy of specialized professional skills — and the forms of instruction or work experience associated with them — for success on the contemporary labor market.

Education systems reacted to the increased demand for soft skills over hard, narrow ones by increasing the share of students studying humanities-based subjects and teacher education (from 19% to 24% of bachelor's students in Norway, France, Great Britain, and Germany, but only 12% in Russia [*Kliachko,* 2017, p. 24]. Another response to this demand was the spread of new universities following the classic liberal arts model of education. Studies show [*Telling,* 2018] that students in highly developed countries are most likely to prefer this model of education because of its ability to open doors to

a large spectrum of potential professional trajectories. Liberal arts students are not in danger of being trained as a specialist in a field that is dying or not in demand, which is an appealing advantage in the face of growing doubts about the effectiveness of mass higher education systems [*Telling,* 2018].

The deficit in general human capital has also been reflected in the widespread addition of entrepreneurial elements to curricula, including in secondary and tertiary education. Countries with leading positions in the innovation economy have been the most active in this area. In Finland [NAE, 2014] and British Columbia, Canada, an entrepreneurial component is part of the "technology" curriculum. In a paradoxical turn of events, the tertiary education sector, which traditionally specializes in producing specific human capital and specialized work skills, has become increasingly permeated by entrepreneurial education. This is especially noticeable in countries and regions at the forefront of technological progress. The largest intellectual hub of Silicon Valley, Stanford University, has significantly boosted its entrepreneurial offerings over the last twenty years, including programs within technical and software disciplines. According to one large-scale survey in 2011, more than one third of Stanford graduates started their own business, and a similar percentage have experience working at a startup. More than half of the graduates that became entrepreneurs said that Stanford's entrepreneurial spirit was what drew them to the university [*Eesley, Miller,* 2018]. All told, Stanford graduates founded almost 40,000 companies and created more than 5 million jobs, generating annual revenue of $2.7 trillion [*Eesley, Miller,* 2018].

The tertiary education sector in Russia is also showing a distinct tendency towards renewal, but the impact of entrepreneurial education on the economy remains small. Businesses created in collaboration with universities have so far failed to compete effectively [*Karpov,* 2018]. Whereas the Massachusetts Institute of Technology (MIT) incubates more than 150 new companies annually, 24 of the top 40 Russian universities generated less than ten startups between 2009 and 2015 [*Karpov,* 2018]. Nevertheless, a net positive effect of specialized entrepreneurial training has been proven for the development of Russia's business ecosystem. [*Dukhon et al.,* 2018].

A question remains about which specific elements of entrepreneurial training stimulate growth. Is growth driven more by specific know-how in business administration, by soft skills like leadership and cooperation, or by a broader culture of creativity and innovation? Expanding on Blaug's initial idea, we can surmise that the effects are cumulative, and that the diverse array of programs such as entrepreneurship in digital technology, social entrepreneurship, and corporate entrepreneurship foster both personal initiative and the skills to capitalize on it. Such universal competencies turn out to be valuable for a multitude of different roles on the labor market and in a variety of structural and cultural contexts. As an important and yet little-understood element of general human capital, entrepreneurship demands further study.

Contemporary Studies in Human Capital as Support for an Evidence-based Education Policy

In order to execute an evidence-based policy for developing human capital it is not enough to simply acknowledge the rift between the needs of the labor market and the output of the education system, whether in terms of which programs of study are chosen or which skills are taught. Creating effective education policy instruments requires that we understand, on one hand, which specific elements of human capital are most important, and on the other, which conditions and mechanisms can bring these elements to fruition in practice. Without this, the growth of "undercapitalized human potential" is inevitable, and we will continue to see people with valuable skills who are not fully integrated into the economy, are unable to find jobs, or do not have the skills necessary to grow in a way that would benefit themselves and society as a whole.

Beginning in the 1980s, many researchers have worked towards creating conceptual models for specific components of human capital. These studies fall into three general categories which are directly linked to the emergence of new datasets. The first category looks at domain-specific cognitive skills, whether within a profession or a discipline. The second category focuses on the study of noncognitive skills and personality traits. The third category analyzes employer demand for universal, foundational, or key competencies, which include both cognitive and noncognitive elements.

Studies of "Traditional" Cognitive Skills

Standardized testing of knowledge and skills emerged in the beginning of the twentieth century and became widespread in the 1930s but was used mostly for student selection and military recruiting [*Gibby, Zickar,* 2008]. National standardized assessments of education outcomes that could be used for studies rather than just the selection of human resources entered the mainstream in the second half of the century. Large-scale international assessments of education quality became available in the 1980s [*Kamens,* 2015], and made a significant impact upon the theory of human capital.

In the late 1980s, Erik Hanushek brought together the results of the new international assessments with economic data and put forward his thesis [*Hanushek,* 1986]. He asserted that it was not so much the increase in years of schooling and degrees granted that had an impact on economic growth, but rather the increase in the quality of human capital, as mea-

sured by the development of cognitive abilities. This thesis is now confirmed by large-scale comparative studies conducted by the World Bank [*Lange et al.,* 2018].

Hanushek's assessments of educational quality made use of the set of metrics that was available for analysis on a national level and for international comparison. Since practically all the countries in the world adhere to traditional disciplines in education, researchers used international TIMSS and PISA results, especially in math and natural sciences, to measure cognitive skills [*Hanushek, Woessman,* 2007].

Hanushek and his colleagues showed a high degree of explanatory power in the data collected by international assessments of education outcomes when applied to subsequent rates of economic growth. In large part, this was the main catalyst for respected institutions like the World Bank [*Lange et al.,* 2018] to start paying close attention to cognitive skills, which can provisionally be defined as: *The ability to process information (in text or numerical form) and subsequently make a decision or solve a problem using logical reasoning and the creation of new ideas* [*Hanushek, Woessman,* 2008].

In 2017, however, a study conducted by Hikaru Komatsu and Jeremy Rappleye raised questions about the validity of Hanushek's thesis in the twenty-first century and asked whether there was still a high degree of explanatory power in subject-based testing vis-a-vis economic growth [*Komatsu, Rappleye,* 2017a]. The authors showed that while the explanatory power for the last decades of the previous century (using R-squared) was quite high (>35%), in this century it decreases significantly (<20%). Looking beyond Komatsu and Rappleye's own arguments, one possible reason for this effect might be that such tests fail to reflect a number of components of human capital that are necessary for the contemporary economy. Additionally, there are major differences between the TIMSS and PISA assessments which must be taken into account. If the former has always been intended as a tool for measuring how well students were learning a given school subject, the latter has sought to approximate, if only in test form, the practical application of knowledge. One of the possible explanations for Komatsu and Rappleye's discovery, then, could be that as a narrowly subject-based test TIMSS does not provide information about general skills important for the twenty-first century. PISA, with all its shortcomings, at least partially solves this problem, and in fact continues to move towards a greater assessment of universal competencies while remaining largely a test of subject-based cognitive skills.

The scholarly community today has not come to a consensus about the usefulness of data from international assessments of education quality in explaining economic growth. According to David Kamens [*Kamens,* 2015], the correlation between students' test results and economic growth strengthened after 1990, thanks to an increase in the number of participating countries and an expanded capacity for selection within each country. John Meyer, Francisco Ramirez, and their colleagues concluded that there was a nonsignificant correlation between test scores and national economic growth, but even that was only evident when rapidly growing Asian countries were included in the study [*Ramirez et al.,* 2006]. In general, the lack of consensus on this matter does not mean that cognitive skills are not a factor in economic growth, and in fact it is most likely that they do have a significant impact. However, the situation does suggest that the role of education is not reducible to the cognitive component of human capital.

"Fluid Intelligence" and Personality Traits as Noncognitive Skills

James Heckman, Tim Kautz, and their colleagues have critiqued the types of academic achievement testing on which PISA is based, claiming that they "... do not adequately capture noncognitive skills—personality traits, goals, character, motivations, and preferences that are valued in the labor market, in school, and in many other domains. " [*Kautz et al.,* 2014, p. 2].

The authors view noncognitive skills not as innate personality traits, but as abilities that can be taught. Meanwhile, traditional testing, including PISA, focus only on one aspect of intelligence, which has been called "crystallized intelligence" in the scientific literature; i.e., on already processed knowledge. "Fluid intelligence" cannot be measured by standardized tests, since one would need to assess how well a person learns rather than how well they apply things they have already learned [*Kautz et al.,* 2014, p. 7].

Looking at numerous studies, mostly conducted in the US during the last quarter of the twentieth century, Heckman and his colleagues established that "achievement tests," i.e., tests of cognitive abilities given to teenagers, can explain only 17% of the difference in income when they become adults [*Kautz et al.,* 2014, p. 2]. If one looks at the explanatory power of once-popular IQ tests, it is only about 7% [*Heckman, Kautz,* 2012]. By analyzing the wealth of research carried out by American psychologists, Heckman was able to assert that noncognitive traits were of greater importance for success both in school and in life.

The authors defined noncognitive skills as "all personality traits that are not measured in traditional achievement tests" [*Kautz et al.,* 2014, p. 8]. The goal here is to create a method of analysis for the "significant, but not fully described" elements, which appear in the theory of the resource-production ratio as entrepreneurial abilities. Heckman bases his criteria on the so-called "Big Five" theory [*Judge et al.,* 1999]:

- Extraversion;
- Agreeableness (friendliness, ability to come to consensus);
- Conscientiousness (awareness, including responsibility, the ability to follow a plan, executive ability);
- Emotional stability (a term describing the general ability to act rationally in stressful situations, as opposed to emotional instability and impulsiveness);
- Openness to new experiences.

Citing the meta-analysis of empirical studies [*Barrick, Mount,* 1991], Heckman points to a statistically significant correlation of 0.22 between labor output and the "conscientiousness" element of the Big Five.

One of the most compelling comparative studies on the significance of cognitive and noncognitive traits of teenagers vis-a-vis their working life as adults was conducted by Heckman himself, along with his colleagues [*Kautz et al.,* 2014]. The researchers looked at two groups of American students: those who graduated from high school in a traditional campus setting, and those who did not finish all twelve grades but took a high school equivalency test of cognitive ability, the General Education Development test. It turned out that although both groups demonstrated essentially the same level of cognitive ability as measured by achievement tests, there were significant differences in noncognitive abilities and subsequent differences in income. In particular, parameters such as openness to new experiences and agreeableness had stronger correlations with subsequent success in education and in the workforce than "traditional" cognitive traits [*Kautz et al.,* 2014]. These conclusions prove the validity of psychological and socio-psychological aspects of human capital, which can be interpreted as an expansion on the "general component" of human capital.

Another of Heckman's arguments in favor of promoting the development of noncognitive skills through education policy is based on surveys of employers in the US and Great Britain. These place a higher value on skills such as "executive ability," "teamwork," or "working with clients," than literacy and arithmetic [*Kautz et al.,* 2014].

Furthermore, the authors claim that noncognitive skills are more amenable to change than cognitive ones. In the context of human capital development, Heckman concludes that the noncognitive aspects should be the center of attention for the education system.

Universal Competencies as Undervalued Elements of Human Capital on a Changing Labor Market

Many researchers of human capital have counterposed cognitive and noncognitive traits. Since both are recognized as valuable, they are slowly being integrated into a single conceptual framework. An important step in this process has been the discussion of universal basic skills [*Ludger,* 2015].

The international tests discussed above are directed primarily towards assessing routine and discipline-specific skills, such as knowledge of specific mathematical formulas and the ability to make calculations without errors. These cognitive skills can be called traditional insofar as they adhere to a conventional image of a "smart" person from the early twentieth century, equating education with erudition in the sense of having a large body of knowledge in a narrow set of disciplines. The overall effect is essentially one of prioritizing specific human capital, which is more true of TIMSS than of PISA. The latter places more emphasis upon meta-subject learning while maintaining a focus on mathematics and physical sciences.

Unlike Hanushek and Heckman's investigations, the theory of universal competencies, starting with the 1970s, has looked less towards finding empirically proven links between specific skills and subsequent economic success (whether by individual or by country). Instead, it takes as a starting point the direct needs of the labor market and the business community, which has slowly been learning to articulate its requirements for generic skills [*Slavendy,* 1969].

Rigorous investigations at the end of the last century showed significant changes in the types of labor over the preceding decades. Overall, they reflect a growth in non-routine tasks as well as in the volume of work based on communication (Figure 1) [*Levy, Murnane,* 2013]. This is directly linked to the growing role of universal competencies, including communication skills, cooperation, analytical thinking, creative action, and others, which together form the core of a new understanding of human capital for the twenty-first century [*Levy, Murnane,* 2004; *Anikin,* 2017].

The tests on which Hanushek based his work did not measure skills like critical thinking, self-direction or communication. However, contemporary discussions of education are more and more interested in measuring universal competencies. In 2015, the PISA program, one of Hanushek's primary sources of data, augmented its testing with sections for measuring problem-solving ability in groups. This work is set to develop further, for example with new tools for measuring entrepreneurial ability or creativity [*He et al.,* 2017].

Compared to their peers working in the same industries 30 or 50 years ago, contemporary workers are much less likely to have to apply, for example, subject-based math skills: calculators are available on even the most basic smartphones [*Levy, Murnane,* 2013]. However, the most basic cognitive skills are still in high demand, as has been demonstrated by studies such as PIAAC, conducted by the OECD. These studies show a strong correlation between the

cognitive literacy of the adult population and macroeconomic indicators, for example in European countries [*Woessmann,* 2016]. It is also worth noting the high level of congruence between the results of PIAAC and PISA, as noted by OECD experts [OECD, 2016]. Additionally, European studies have empirically proven a positive effect on national economic growth of applying cognitive skills in the workplace [*Valente et al.,* 2016]. Recent international studies have also shown that PISA results have a significant impact upon the entrepreneurial activity of a given population [*Hafer, Jones,* 2015].

Ultimately, basic subject-based cognitive abilities often serve as the foundation for learning more complex meta-subject skills and are positively correlated with certain noncognitive skills. This was demonstrated by a meta-analysis of studies about links between cognitive skills and the Big Five personality traits among adults. Certain traits, such as openness to new experiences show a strong positive correlation with cognitive skills [*Curtis et al.,* 2015].

At the same time, the relationship between subject-based cognitive skills, universal basic skills, and personality traits is complex and not direct [*Stankov,* 2018]. Special effort is therefore required to develop universal, soft skills for the twenty-first century and the noncognitive components of human capital.

Fundamental Differences between the Ideas of Heckman and Hanushek for Education Policy

Hanushek and Heckman come to differing conclusions about the aspects of human capital that are most important for economic growth, and what recommendations to make for education policy.

Hanushek emphasizes relatively traditional, subject-based cognitive skills and gives priority to formal schooling, especially mathematics and natural sciences. Using the PISA model of assessment, a large number of studies were conducted in specific countries in an attempt to bring to light which aspects of national education systems were responsible for the best test results. The key success factors traditionally cited in education policy circles are [*Deng, Gopinathan,* 2016]:

- The quality of teachers;
- Modern school administration practices;
- Effective system for assessing learning outcomes;
- Systemic reform of the educational process directed towards stimulating initiative, independence, and creativity in students.

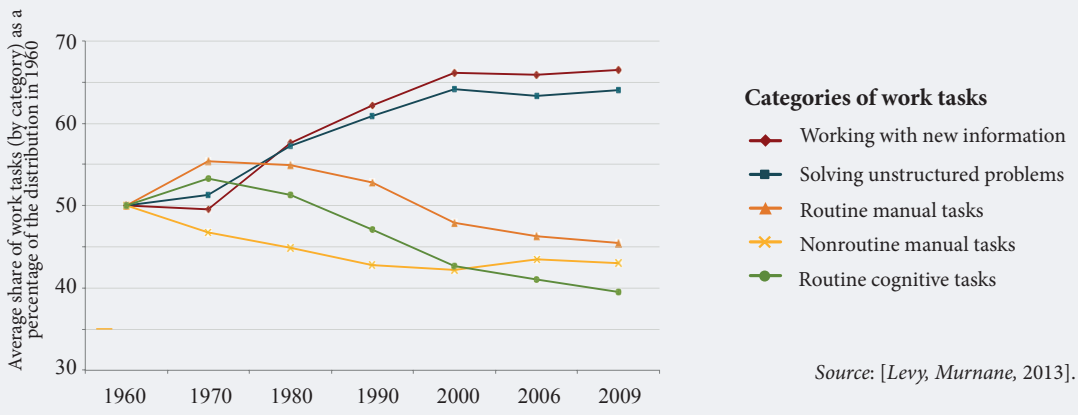
The last point acts as a kind of bridge between traditional subject-based cognitive skills and the more complex, universal, and noncognitive ones discussed by Heckman. In his opinion, however, the priority must be to go beyond merely finding the right content for classrooms or finding highly qualified teachers: we must look for new ways of organizing the education process as a whole. A large-scale review of interventions in the US education system [*Kautz et al.,* 2014] shows the strong potential of projects that engage students in constructive, applied activities, such as industrial processes outside the framework of formal education.

New Findings in the Study of Human Capital and their Impact on Education Policy

The PISA Effect

After the significance of the cognitive skills measured by PISA became universally accepted, the term "PISA shock" emerged in the literature [*Pons,* 2012]. The term describes the effects of unexpected assessment results on national education policies and even on the self-conception of ordinary citizens. Germany in the 2000s is a negative example of this, while Portugal in the 2010s is a positive one. There are numerous well-known examples of interventions

Figure 1. **Changes in the Nature of Labor in the US Market, 1960-2009***



Source: [*Levy, Murnane,* 2013].

in school systems directed more or less explicitly towards raising PISA test scores. Current attempts to modernize the Russian school system are following a similar path.

Research conducted by McKinsey [*Mourshed et al.,* 2010], encompassing around 575 specific interventions in twenty local school systems, confirmed that the actual content of school curricula in the vast majority of countries is directed towards maintaining traditional approaches of drilling and routine cognitive tasks, i.e., teaching rather than learning. Education systems maintain a strict disciplinarian character and are insufficiently proactive in supporting creative, team-based, and project-based work.

The track record around the world indicates that contemporary education systems have not yet figured out how to develop the array of skills needed to produce general human capital for the twenty-first century. Even if we limit our view to those countries that have been recognized for achieving breakthroughs in PISA, we will find a gap between the idea of "best practices" and the reality of concrete reforms.

The example of Singapore [*Deng, Gopinathan,* 2016] shows that the decisive element in the country's success was not the widely lauded set of universal decisions such as the recruitment of top graduates into teaching, the development of a system of continuing education for teachers, or the modernization of curricula. Rather, it was contextual factors, including national cultural traits (such as Confucian values, which are also present in other Asian countries that perform well in PISA) and institutions (the "high stakes" model increases the importance of achievement in high school). Singapore, however, officially declared in 2011 that they would shift the paradigm of education from developing skills directly for use in the workforce to developing the person in a broader understanding of the term and transcending the specific needs of the labor market [*Reimers et al.,* 2019].

Another PISA star, Finland, illustrates the primacy of contextual factors over "best practices." Despite the OECD's efforts to promote innovative teaching practices, which are seen as such an important element of PISA success, Finnish teachers practice traditional methods. Their work is supported by the high degree of social trust and professional status accorded to school workers in Finland [*Simola,* 2005].

Finland, Singapore, South Korea, Japan, and other leading countries in the PISA rankings all have a strong emphasis on mathematics courses, natural sciences, and languages in common, rather than the types of general competencies suggested by the OECD as paths to PISA success [*Waldow et al.,* 2014]. The example of Russia is instructive, since the PISA methodology has been taken up as the official instrument for measuring education quality. This includes the national-level project "Obrazovanie," or "Education." The lack of tangible improvement of the national outcomes in these ratings is used as evidence to justify keeping in place the same archaic school models that the OECD is trying to modernize.

Komatsu and Rappleye's comparative study showed a negative correlation, on the level of average PISA scores by country, between national indicators of functional social science literacy and the average level of independence, interest, and motivation of students when studying the same disciplines [*Komatsu, Rappleye,* 2017b].

Finding an answer to the question of PISA's cumulative effects has turned out to be a difficult task. Despite what the OECD asserts, universal solutions such as developing innovative teaching methods or focusing on general competencies as a way of raising the quality of education are most often secondary in significance compared to local cultural and institutional contexts, which even in leading countries keep their traditional character and prioritize learning over teaching. When it comes to innovative pedagogy, there is the issue of insufficient growth. A set of case studies, which included Russia, showed that there was no noticeable change in the basic teaching processes in leading countries. The idea of fundamentally transforming education systems to shift towards fostering initiative, independence, and creativity remains in the realm of expert discussions and isolated experiments.

There has been growing debate around how the education system can strive to foster "agency" in students. This usage of the term is different from the one used in institutional economics in the framework of "principal/agent," where the agent is seen as dependent on the principal and acts in a purposeful, rational manner to maximize personal benefit within institutional boundaries. Rather, we are using agency in the sociological sense, and looking at it through the framework of "structure/agency" [*Udehn,* 2002], in which agency is a force capable of changing structures and institutions, not just reinforcing them. In this context, agency is synonymous with initiative, active independence, or transformative, expansive action.

Experts in this field are more and more likely to view agency as a value in itself, not reducible to other skills or components of human capital [*Estrin et al.,* 2016; *Bosio et al.,* 2018]. However, this approach is not in the forefront of most countries' education policy. The recent OECD project Education 2030 may be the exception, since it looks at agency as both a key outcome of and a condition for education [OECD, 2018]. It seems ultimately that the issue is not simply that the OECD's solutions are not universally applicable, but also that countries are not transforming their education systems actively enough.

Developing Noncognitive Skills through the Education System: Lessons for Policymakers

Heckman and his colleagues, who did a detailed survey of all the notable interventions aimed at developing noncognitive skills (mostly in the US) in their report to the National Bureau of Economic Research (NBER), pointed out that such skills had only been accepted as valuable by experts in recent years. This explained the lack of major national projects in this sphere. The authors also point to the dearth of data on the effectiveness of interventions aimed at fostering noncognitive skills in students beyond childhood. There are very few examples of such efforts, at least in Heckman's main area of interest, the US.

Summarizing the conclusions drawn from the experiments, which were largely run in low-income and problem student populations, the researchers report that programs limited to in-school activities had a limited impact upon teenagers, as compared to mentoring or apprenticeship programs based in the workplace. A large portion of the interventions analyzed showed no positive effect and in some cases even showed a negative one [*Kautz et al.,* 2014]. Issues arose in part with programs that immersed participants in a rigid system, thereby depriving them of a sense of autonomy and the confidence of being able to solve a problem independently [*McCord,* 1978]. In other cases, the reasons for the lack of success may have been the opposite extreme, where participants felt protected and supported no matter how poorly they performed individually [*Rodriguez-Planas,* 2010].

The significant distribution in the effectiveness of the projects analyzed by Heckman, including negative values, points to the lack of readily available and tested solutions on the part of the education community for fostering noncognitive skills (especially among older children and teenagers).

It is therefore easier to figure out how to stimulate self-sufficiency, grit, and other such traits in individuals than it is to adapt education systems towards developing personality traits [*Ng-Knight, Schoon,* 2017]. The leading research centers are working hard towards developing corresponding metrics but are still far from reaching this goal. In practice, most countries including Russia have failed to fully integrate Heckman's key insight about the impact of personality traits upon personal success. This can partially be explained by the lack of consensus around a proven instrument for measuring these kinds of traits. More importantly, however, is that even when such an instrument exists, actual practices within the pedagogical community have so little to offer in terms of fostering these traits that only the most successful education systems of traditionally leading countries have the capacity to attempt to develop them. Singapore, for example, is already a PISA leader, but now is conducting experiments to integrate formal and informal teaching on the basis of new technology [*Looi et al.,* 2016].

Developing Universal Competencies as a Practical Challenge for Education

The rise of concepts like "core competencies" and "21st century skills," thanks in part to the efforts of the OECD [*Ludger,* 2015], has been an important step towards bridging the gap between the practice of education and the needs of the times. The demands associated with these terms have made their way into the national education standards of the majority of OECD member countries. However, the lists of competencies used by countries and institutions differ significantly. Russia has been active in the international debates and Russian experts have tried to formulate their own list of key competences. Many existing classifications use a combination of three main categories: cognitive traits (such as higher order thinking), social traits (such as communication skills), and socio-psychological traits (such as positive self-image) [*Frumin et al.,* 2018].

The specific formulation and indicators of key competencies continue to lack focus and often overlap, which prevents the international community from reaching the same kind of consensus as with PISA instruments or the Big Five personality traits. A lack of accepted mechanisms, in turn, makes it difficult to develop a set of well-founded practical recommendations. There is uncertainty about both the effects of a supposedly universal skill on individual achievement, as well as the question of education's role in fostering it.

In numerous countries and regions such as Finland and British Columbia, the methods described earlier for developing entrepreneurial skills in the context of formal education have already been implemented as required elements of the school curriculum. This alone makes them worth looking at in the context of universal competencies. At the same time, entrepreneurial education is among the methods most highly criticized in the professional literature, despite its growing popularity. Existing models have been declared insufficiently effective, while proposed alternatives demand radical changes in teaching methodology while also being non-responsive to new discoveries in the field of human capital. Most of the proposed ideas are in the form of boutique programs rather than mass-scale solutions [*Oosterbeek et al.,* 2010; *Martin et al.,* 2013; *Neck, Green,* 2011].

The Gap between Theory and Practice in Human Capital Development

A cumulative analysis of studies of education practices and various components of human capital yields a wealth of material for further research and policymaking. Two key components of human capital can be said to influence both individual success

and economic development on a national level: cognitive (subject and discipline-based) and noncognitive (including the Big Five personality traits) skills. Many experts emphasize the former as being more important.

Still, there seems to be no universal solution for the problem of developing either aspect of human capital within the framework of national education policies. At first glance, it looks like there is a consensus around the basic instruments that can be used to develop cognitive skills, but detailed analyses of success stories like Singapore [*Deng, Gopinathan,* 2016], Finland [*Simola,* 2005], Korea [*Waldow et al.,* 2014], and Japan [*Komatsu, Rappleye,* 2017a,b] raise serious questions about the validity of this consensus. The ways in which noncognitive skills can be developed have not been studied sufficiently and there is an absence of solutions that are recognized to be effective, with the exception of a generally accepted hypothesis about the effectiveness of mentoring and apprenticeship programs tied to specific professions and workplaces.

Despite the rapid growth in the costs associated with education reform around the world, experts agree that national education systems are not very effective at raising the level of human capital. The key to understanding the mismatch between increasing investment in education and economic growth may be found at the level of institutions. The ways in which education is organized, its content and methods, do not match up with the criteria that have been developed within human capital theory over the past half century.

Another sign of the disconnect between education policy and theories of human capital is the lack of consensus around instruments for measuring cognitive and non-cognitive traits that are relevant for post-secondary education, not counting the level of salary after graduation. University rankings are geared towards measuring scholarly output rather than student traits relevant to human capital and there is no system for testing the quality of vocational training.

A key instrument for university oversight from the point of view of human capital is keeping track of graduate job placement, not only by university but also by major—including salary data. In Russia, centralized systems of statistical monitoring by the government and central oversight of universities make this task easier [Ministry of Education and Science, 2016]. The advantage of the Russian approach, in part, is that data gathering can be done on the basis of objective data from the Pension Fund rather than self-reporting.

However, Russia finds itself at a disadvantage even in this sphere. Statistics on salary and employment data for graduates are gathered in all advanced economies, in one form or another. For example, the US Bureau of Labor Statistics (BLS) publishes both official salary data and self-reporting from various categories of respondents, including education data not linked to specific colleges and universities. Data about the latter is gathered via special (non-annual, and therefore limited) surveys conducted by the US Department of Education.

Nevertheless, even the most detailed information does not make up for the lack of real data about the skills possessed by graduates or of those components that result in a return on human capital. It will be necessary to conduct studies, including international ones, on the professional competencies of students and graduates [*Loyalka et al.,* 2019]. So far, there have not been many of these done.

New Challenges to the Theory of Human Capital

One of the main challenges of the situation described above is the lag in implementation on the part of education policy. Theoretical developments in the study of human capital, both specific (which we associate primarily with subject-based knowledge and skills) and general (associated with universal basic skills and personality traits), have not been implemented at scale. There exists an equally serious challenge for the education system, however, which has been underestimated in the work of Heckman and Hanushek. Before going further, we would like to highlight some important similarities in their two approaches, having already analyzed the major differences:

1) The thesis of "homogeneity in time." Both concepts include obvious or hidden assumptions about the stable and unchanging nature of basic socioeconomic conditions in developed countries over recent decades. The relative importance of both discipline-based and noncognitive skills is treated as something like a constant. In the case of Hanuschek, this is done explicitly: the figures for cognitive subject-based skills are built into his regression models for GDP. Heckman does not build regression models stretching over a half-century, partially due to the lack of representative data. However, his argumentation itself leaves no doubt that the environment is an unchanging one. For example, a significant portion of his arguments are based on studies conducted in the first half of the twentieth century, when personality traits were recognized as a factor of success by psychologists, while the Big Five model only appeared in the 1960s.

2) The thesis of "homogeneity in space." Both researchers assume that the laws of human capital development they describe are universal not only time, but also in space. In the work of Hanushek, this is directly revealed in the universal regression model, or "success formula," and the thesis that follows from it, in which the effect of raising average PISA scores for any country by one standard deviation has the same

effect on the economy [*Hanushek, Wowssmann,* 2010]. Heckman also directly asserts the "universal value of noncognitive traits across cultures, regions, and societies" [*Kautz et al.,* 2014, p. 2].

3) Following classical postulates of economic theory, both authors accept the possibility of directly extrapolating from the return on human capital at an individual level (in the form of higher wages for more educated/higher skilled workers) to cumulative return at the level of society as a whole (in the form of GDP growth and other macroeconomic indicators). Because of this, the aforementioned micro/macro paradox goes unnoticed, as does the problem of the middle-income trap.

We view these aspects of the two authors' work as excluding the possibility for human capital to directly influence the formation and evolution of economic institutions. The aspects of human capital analyzed by Hanushek are related to "modern" jobs, which are supposed to already exist at the moment in time when human capital enters the labor market. Heckman, meanwhile, seems to attend mostly to the social aspects of work. He shows the importance of developing not just universal cognitive skills that are directly valuable for solving on-the-job problems, but also those that allow one to successfully live amongst other people, build relationships, and solve problems together. Heckman also looks at individual traits that allow one to adapt to already existing institutions, rather than push for the creation of new institutions. It is not surprising, then, that his prime example of mechanisms for developing noncognitive skills are traditional nineteenth-century formats like mentoring and apprenticeship [*Kautz et al.,* 2014].

These common assumptions inherent to Hanushek and Heckman's approaches have a major influence on contemporary education research as well as policymaking in this field. Their approaches are not fully sufficient, however, to confront the new challenges facing human capital development, which are discussed below.

The Role of Human Capital in Socioeconomic Development in the Twenty-First Century: New Challenges and the Goal of Fostering Agency

The ever-changing nature of contemporary business has reached a level that would probably have been unimaginable in 1975, when Theodore Schultz conceptualized the capacity for action in situations of uncertainty. Schultz highlighted a specific, entrepreneurial aspect of human capital, "allocative abilities," which allowed a person to manage his or her knowledge and skills, position them in an economically sound manner, and find the optimal use for them in business. In his Nobel lecture on December 8, 1978 [*Schultz,* 1978], he underscored the fact that the abilities he had written about were important not only on the labor market, but also in the household and when making decisions about one's educational trajectory. Schultz claimed:

> Human capital contributes to labor productivity and to entrepreneurial ability. This allocative ability is valuable in farm and nonfarm production, in household production, and in the time and other resources that students allocate to their education. It is also valuable in migration to better job opportunities and to better locations in which to live. [*Schultz,* 1978].

Schutz's approach differs from other models in that it rejects the idea that human capital immediately and automatically reacts to the situation presented by the labor market. Even when there is a direct market demand, far from everyone is willing to relocate to a new city, retrain for a new profession, and change jobs in search of a better life, meaning that not everyone possesses the decisively important abilities to achieve individual success. Unlike Schumpeter, who saw entrepreneurial abilities as a kind of natural talent unrelated to the economic situation, Schultz insisted that the education system increased a person's effectiveness in a situation of unpredictable change, instability, and risk [*Piazza-Georgi,* 2002].

Despite how often Schultz is cited, especially in the literature on economics [*Acemoglu, Restrepo,* 2018], management, and innovation [*Lundvall,* 2010], his main idea about the entrepreneurial component of human capital has remained on the periphery of contemporary debates about education [*Klees,* 2016; *Tan,* 2014; *Marginson,* 2017], even though it began to be discussed back in the early 2000s [*Piazza-Georgi,* 2002]. It is evident, however, that Schultz's approach provides convincing material for arguing against critics of the theory of human capital and its usefulness for education policy [*Klees,* 2016; *Tan,* 2014; *Marginson,* 2017]. The growing number of entrepreneurship programs in the tertiary education sector can be seen as a pragmatic solution appearing naturally within the system and gaining more and more traction on the free market. However, the attention being paid to the entrepreneurial component of education remains insufficient and pro forma. Only a handful of countries and regions have integrated systematic entrepreneurship training into the school curriculum. Unfortunately, the growing number of such courses of study in the tertiary sector has not come with a corresponding rise in quality, even though there has been a visible effect on new business startups, including in Russia [*Dukhon et al.,* 2018].

From our point of view, the tectonic shifts of the past decades have not been sufficiently reflected in the political arena. They require not only that we finish building the current projects, but also that we totally rebuild many elements of the education system.

The volatility of today's economy and the instability of certain companies is due not so much to bad strategic planning, as to objectively rapid changes in technology, which also demand new skills on the part of workers [*Bessen,* 2016]. The idea of a vocational training that lasts a lifetime does not match up with the contemporary trends in technological and social development. As noted in the report on trends in human capital by Deloitte, professional skills need to be refreshed every five years, whereas a career may be expected to last 60 or 70 years [Deloitte, 2017, p. 30].

The trends described above are reflected in the growth of the global service sector [ILO, 2018], the percentage of the workforce working as freelancers, which could reach 50% by 2027 [Upwork Global, 2017], as well as in the growing role of small and micro entrepreneurs in creating jobs around the world [*Li, Rama,* 2013], all of which serve to disprove the thesis about homogeneity in time. The world is changing, which means that the importance of certain elements of human capital may also be changing, along with the mechanisms by which they can be capitalized upon in the economy. Taking into account the uneven pace at which different countries enter into the fourth industrial revolution, the thesis of homogeneity in space — even within a single country — is put into doubt. This is especially relevant for such differentiated economies as Russia and China, where high-performing sectors exist side by side with poorly performing ones.

One powerful aspect of technological change driving many of these trends is the rapid growth of platforms for the sharing economy, which frees participants from the structural limits imposed by traditional ways of organizing business (at least in big cities and economic sectors with a high rate of technology penetration). Buyers, sellers, partners and clients are more and more likely to deal directly with one another via platforms, with public user reviews serving as quality control. The large sets of data that result from this are analyzed with the help of artificial intelligence (AI), allowing precise models of market trends to be created.

Changes in economic behavior resulting from the new platforms can be interpreted in various ways, from total denial of the platforms' structural importance to deeming them harbingers of the end of the market economy, which will be replaced by fundamentally new, altruistic forms of economic management [*Arvidsson,* 2018]. Other researchers believe that the platforms do not decrease competition, but rather escalate it [*Arvidsson,* 2018]. Some see the reconfiguration of the economic behavior of platform participants as increasing the demand for aspects of human capital such as creativity, as well as social skills like the ability to form relationships based on solidarity [*Carfagna,* 2018].

The trends in the Russian economy, such as growth in retail sector employment and diminishing numbers of high-tech jobs, seem incompatible with the new technologies that are transforming the landscape of the contemporary economy. In fact, these two trends complement one another. The loss of manufacturing jobs has increased the number of people who categorize themselves as self-employed, without a permanent job, or freelancing, from 10% to 18% in just the year 2017 [National Agency for Financial Studies, 2017]. In addition, new technologies allow workers not only to opt out of traditional forms of corporate employment, but also to easily transcend geographical boundaries. According to RBC, a large share of Russian freelancers work for foreign clients [*Li,* 2017]. The result is a shift in the traits of organizations and individuals that enable them to find stability in uncertain situations. It may be the case that under such conditions, the key factors in boosting economic growth rates may be found not only in institutions, but also in the know-how of managers [*Acemoglu et al.,* 2006].

A high level of training and skill may be far from the only factors in being successful in contemporary business. The literature on management is coming to embrace such terms as "entrepreneurial organization" [*Kirkham, Mosey,* 2017], "entrepreneurial manager" [*Cook,* 2017], "entrepreneurial behavior" [*Jong et al.,* 2015], and so on. The term "transformational human capital" [*Ling, Jaw,* 2006] describes employees' capacity for corporate entrepreneurship in a broad sense, for example, proactively improving the company, its products, and working methods, which is considered to be within the purview of every employee [*Birkinshaw,* 1997]. This approach is embodied by the famous Japanese management system, which produced unprecedented rates of economic growth in the twentieth century [*Suzuki,* 2016]. One of the key traits of the Asian model of corporate management, most famously implemented in the Toyota management system [*Liker,* 2001], is constant oversight of business processes, not for maintaining the current system, but with the goal of finding and implementing rationalizing measures with the help of all employees. The Japanese system offers an alternative to the Western model of Weberian bureaucracy [*Udy,* 1959], with its narrowly functionalist specializations and strict hierarchies of subordination for carrying out approved directives.

The "new middle class" [*Anikin,* 2017], composed of the corporate elites that solidified their position at the top of the social pyramid in developed countries between the 1960s and 1980s, is being moved aside by other social groups vying for preeminent status as the corporate sector shrinks around the world, including in Russia. These groups include workers in the creative industries, highly qualified freelanc-

ers, and a new breed of entrepreneurs who not only eschew traditional corporate norms, but openly oppose them [*Hesmondhalgh, Baker,* 2010].

Furthermore, entrepreneurial skills are valuable not just for future entrepreneurs. A recent study of 18 OECD countries showed that these skills are important for today's graduates seeking careers in the corporate world. In other words, what we are dealing with is not so much entrepreneurial skills in the literal sense, which are only really used by a small percentage of the workforce. Rather, it is entrepreneurship understood as an ability to effectively find uses for one's own human capital. For their part, modern education systems reveal their own rigidity in their attempts to teach entrepreneurialism. This area of education, according to researchers, is held captive by traditional forms of pedagogy [*Oosterbeek et. al.,* 2010; *Unger et al.,* 2011].

Education systems around the world are faced with the unprecedented challenge of trying to help every individual succeed in the world of platforms and freelancing. It is a world where habitual institutional boundaries are effaced, as are the boundaries between identity, lifestyle, ambition, and cultural standards [*Meyer,* 2010]. At the same time, there is a growing gap in income and lifestyle [*Picketty, Zucman,* 2014], which is often determined by the nature of one's human capital. Part of this equation is the development of AI [*Brynjolfsson et al.,* 2018], which does not have the capability to replace humans in various professions entirely but can radically change professions and push human beings to the side. Complex routine skills, which were the bedrock of human capital's productivity throughout the twentieth century, are in danger of becoming obsolete. What is needed from the education system in this situation is, first and foremost, developing non-routine skills, both physical and mental, as well as other traits that help students develop and thrive in the world of platforms and AI. Today's workers are asked, essentially, to create a job for themselves and then adapt it to changing circumstances and technologies. Achieving such a goal for any country, including Russia, is possible only with a careful analysis of global trends and a thorough reconsideration of past experiences.

Researchers have offered a number of approaches to conceptualizing the changes happening in society. "Liquid modernity" [*Bauman,* 2005], for example, is characterized by the creation of new structures and forms of sociality (morphogenetic society), rather than reinforcing existing ones (morphostatic society) [*Archer,* 2013]. The British sociologist Margaret Archer writes about the "reflexive imperative in modernity" in terms of an individual's ability to problematize their social context during a sharp increase in the variability of the environment and a diminished role of "habitus." Following the theories of Pierre Bordieu, she writes that modern society is structured by unconscious dispositions for what to do, how to do it, and why [*Archer,* 2012].

The contemporary world demands something more than just high scores on some of the Big Five personality traits. Individuals are expected not only to be open to new experiences, adapt to external changes, and apply themselves to self-development, but also to proactively initiate new social structures and ways of acting. Therein lies a direct answer to the question of the link between human capital and institutions. In this approach, Heckman and Hanushek's frameworks are supplemented with an additional dimension of human capital, namely its role in creating and transforming institutions, also known as institutional entrepreneurship [*Hardy, Maguire,* 2017].

A related dimension, which is developing right before our eyes, is the ability to effectively take action in situations of structural uncertainty, or non-equilibrium, as Schultz calls it. This hypothesis adheres to new ideas in the field of fundamental sociology around the concept of agency. It centers on the question of the connection between social structures and human activity. As mentioned above, institutional economists vary in the ways in which they describe human agency. Bourdieu and Anthony Giddens maintain that an opposition between structures and activity is a false one [*Archer,* 2012, 2013]. However, contemporary studies attempt to measure growth in both institutional variability and the diversity of forms of agency.

These transformations raise some fundamental questions. For example, can individual or collective action set in motion structural changes, and if so, under what conditions? Do "good" structures create "beneficial" forms of agency in society, and if not, how do individuals and groups gain the skills of "institutional entrepreneurship" [*Fligstein,* 2008]? To what extent can the actions of social entrepreneurs be effectively described using the theory of rational action?

The authors of popular concepts like "expanded actorhood" [*Meyer,* 2010], "reflexive monitoring of action" [*Giddens,* 2013], "reflexive imperative" [*Archer,* 2012], "social skills" [*Fligstein,* 2008], and "strategic action" [*Radaev,* 2002] generally recognize the role of individual action in the deliberate transformation of institutions. One key question for our research is: to what extent can education help develop agency (initiative, proactiveness, active independence), given that it is presumed to be the highest priority element of human capital for the new millennium?

Besides the aforementioned sociologists, the most active discussions on this subject are happening among psychologists and theorists of new institutionalism. For example, Ingrid Schoon and her colleagues look at individual and personal mechanisms that allow people to "act in spite of," as Vadim

Radaev has written [*Radaev,* 2002], structural conditions [*Gutman, Schoon,* 2018; *Ng-Night, Schoon,* 2017]. Russian psychologists working with similar topics have analyzed the phenomenon of preadaptation [*Astolov,* 2015, 2017].

Education scholars have accumulated a wealth of insights in the study of agency. In a widely cited article [*Reeve, Tseng,* 2011], agency was looked at as a fourth category of student engagement in the learning process, on top of the traditional three: emotional, behavioral, and cognitive. "Agentive engagement" describes the student's creative input in the learning process, including content and methods. Using quantitative data, the authors show that this type of engagement is both conceptually and statistically different from other forms of engagement in the learning process. The key value proposition of agentive engagement for education policymakers is that it allows students to independently shape their own learning environment [*Reeve,* 2013].

Jenny Arnold and David Clarke [*Arnold, Clarke,* 2014] surveyed the education literature on the subject of agency and found a strong interest among both theorists and practitioners in the idea of transforming the usual learning process into an integrated social activity directed by the students themselves. The authors looked at a wide range of ways of approaching and conceptualizing agency, including critical ethnography, symbolic interactionism, and many others. However, they never mention human capital. We believe that agency must find its place in the theory of human capital and that the work of Theodore Schultz provides one possible avenue of development.

Earlier we tried to show that the literature on the aspects of human capital related to transformation, entrepreneurship, and agency is not limited to academic texts. It also includes management literature, as well as insights from respected names in the business consulting industry. The business world contains a wealth of valuable observations and productive case studies that have as much to offer as all the theoretical baggage accumulated in academia.

The need to foster agency in contemporary education systems does not mean that it should be seen as a universal answer or a substitute for other widely acknowledged elements of human capital.

Due to the decline of traditional frameworks of social unity and solidarity such as family, religion, corporations, and nation-states, as well as the increased atomization produced by new models of economic growth, there is a danger of social polarization and anomie. In this context, it is important to find a balanced approach to developing agency. While some authors see the theory of agency as incompatible with the goal of fostering the transformational, entrepreneurial aspects of human capital through formal education [*Klees,* 2016], we suggest unifying these approaches.

Conclusion

It is likely that by 2030 there will not be a single profession left untouched by the boom in new technologies. According to WEF data [WEF, 2018], the share of fully automated production tasks will increase by 20–50% across all industries in the period between 2018 and 2022 [WEF, 2018, p. 11]. These changes will continue to accelerate, which will further increase the stark inequalities in productivity that exist today both within countries and industries and between them. Those that fall behind in this global race will cede formerly held positions and lose the ability to provide a high standard of living for their changing populations. It is important to keep the demographics in mind, since populations around the world are rapidly ageing. This is problematic, given McKinsey's conclusion [*Manyika et al.,* 2015] that nearly 50% of global growth between 1964 and 2014 came as a result of workforce expansion. Today, this resource is fully depleted and is starting to show a negative trend. Overcoming this challenge and maintaining global GDP growth will require the productivity of each individual worker to multiply.

As we rethink the role of the individual in economic growth, we must distinguish between the ideas of human capital and human potential. It is high time to move on from the notion of the human being as a "widget," produced in accordance with strict standards and placed in a predetermined role in a larger market mechanism. Human capital generated under such conditions is likely to prove counterproductive. A person with an externally proscribed and mismatched skillset is unlikely to find well paid work and risks becoming jobless altogether. An insight into this phenomenon can be found in the low salary premium of less than 10-12% earned by graduates with basic vocational training [*Biliak et al.,* 2011]. In the Russian case, the situation is compounded by the mismatch between the labor market and the needs of an innovation economy, along with other macroeconomic demands. We insist on an expanded definition of human capital, with the following four categories of individual development:

- Specialized skills adapted to specific jobs, as described by the concept of *specific human capital*. According to classical human capital theory, it is created through focused education within a single subject or discipline, as well as work experience. Specific skills can be measured by professional examinations and other rigorous instruments. Attempts to create such assessments in Russia in the past five years have not fully come to fruition [*Murychev et al.,* 2017]. There are several examples of successful exter-

nal corporate assessment tools: CFA[2], Microsoft Certified Professional (MCP)[3], and others. While they do not have a significant impact at the national level, they can evolve into an effective indicator for the development of specific human capital in a given country.

- *General human capital 1* is comprised of universal skills like creativity, critical thinking, learning ability, organization, and the ability to work well with others. It is produced through creative, project-based work and requires supplementing traditional education with new types of collective and independent activities. Recent revisions of the PISA monitoring process by the OECD have made strides towards being able to measure this form of human capital.
- *General human capital 2* includes basic noncognitive traits such as those found in the Big Five, as well as grit, perseverance, psychological adaptability in the face of social changes and challenges, and so on. These traits can be strengthened by specific activities and supported by an increased socio-personal component in traditional education.
- An expanded view of the concept of agency, or active independence, is the basis of *General human capital 3*, which engages with the entrepreneurial element of human capital [*Schultz,* 1978]. This category describes a person's ability to transform social structures and institutions, make improvements in the world in collaboration with others, and create new behaviors, including economic ones. For now, we will leave aside questions like whether agency is an accumulation of cognitive and noncognitive traits or a specific synthesis of the two. Suffice it to say that fostering this element of human capital presents an entirely separate educational task in itself.

Agency will play a key role in redesigning the way jobs are done and in implementing new technologies into labor processes. Not just entrepreneurs, but all workers in the near future will face the need to invent new tools and working methods. A WEF survey of international businesses [WEF, 2018] showed that the world's largest employers do not have any desire to retrain each one of their workers to help them adapt to the demands of a slowing economy and increased competition. The corporate sector is ready to invest in training only for its most productive employees, and even in such cases the expectation is for them to take their own initiative. The rest of the workforce will likely shift to freelance and temporary employment [Upwork Global, 2017, p. 13]. Under these conditions, agency becomes the most important dimension of human capital for competing in the twenty-first century, since success will require workers to independently organize business relationships and create personal partnerships.

Education systems in most countries are still too hesitant to accept new insights in human capital theory, whether from Erik Hanushek's research on the importance of cognitive skills or James Heckman's emphasis on noncognitive personality traits. The lack of dynamism in developing the necessary elements of human capital is reflected in the low rates of growth and socioeconomic progress, despite improvements in official education statistics. If these tendencies continue, some countries may soon see increasingly negative trends in traditional economic indicators such as GDP growth, unemployment, crime rate, and so on. On a subjective level, their citizens will have an increasing sense of social inequality and social tension. Among the highest risk groups are under-qualified workers who may be let go from familiar jobs in the corporate sector and be forced to find their footing on a freelance market for which they are entirely unprepared. In general, all workers who are trained to do routine tasks and unequipped for a non-routine world are at risk.

We must take steps today to develop human capital at the national level, or else we will find ourselves left behind in the global race decades from now. In a recent article, we proposed a number of specific reforms necessary for the Russian education system, both in the short and medium terms [*Kuzminov, Frumin,* 2018]. We hope that this current article will broaden the horizons and increase the scope of the debate surrounding human capital in education.

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Twenty-First Century Skills in Finance: Prospects for a Profound Job Transformation

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Abstract

This paper analyzes the impact disruptive technologies, such as artificial intelligence (AI), big data, the internet of things, and blockchain, upon conventional banking professions and skill sets. Our conclusions are based upon a large array of data collected over the course of a survey of highly qualified personnel conducted in 2017-2018 using text mining, case studies, and expert interviews. The changing requirements for workers and to their competences were assessed taking into account the level of technological development (including the use of relevant products and services by Russian and international companies) as well as the probability of certain professional skills being substituted by automated solutions in the medium term. The results indicate that impact of technologies upon various functional segments of banks' operations is varied. While most of the analyzed professions are evolving towards broader functionality, others are sliding into the "obsolete" group. In the next few years, automated systems will take full responsibility for data collection and its initial analysis, though they will not replace bank personnel fully given that they simply remain tools that help boost workers' productivity and efficiency, extend the information base, accelerate decision-making, cut costs, and reduce risks.

Keywords: 21st century skills; job automation; banking professions; breakthrough technologies; competences for the future

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In recent years many financial organizations have turned into advanced "laboratories", testing grounds for cutting-edge technologies more conservative (or less flexible) organizations hesitate to apply. Many banks have already started to optimize their personnel responsible for handling paperwork and performing routine cognitive tasks, such as tellers, cashiers, controllers, call center operators, client and credit managers, analysts, and consultants. If ten years ago a major problem of the banking sector was optimizing bank branches, now abandoning this format altogether is on the agenda. Financial organizations are trying to morph into autonomous high-tech ecosystems with the smallest possible number of staff.

The application of digital technologies is causing major changes in skill requirements: the demand for new professions is on the rise, while many of the existing jobs are becoming obsolete. The very meaning of the concept of "profession" is changing: the set of competences a worker trained for in a specific profession is expected to cease being definite and static; competency profiles are changing in line with technological and organizational changes, turning into "dynamic portfolios". Accordingly, quantitative measures are no longer sufficient for predicting companies' personnel requirements, while the role of qualitative techniques is increasing. Companies and their HR departments need to adopt the flexible career paths model, taking into account that workers may be transferred between the company's various units due to the full or partial automation of their jobs. The pace of change has been accelerating: the tasks workers have to accomplish are becoming increasingly complex, while predicting skill and competency requirements is steadily turning into an ever greater challenge.

The lack of clear and adequate communications between employers and the education system results in the oversupply of workers with irrelevant competences, combined with a growing shortage of highly sought-after knowledge and skills.

The paper presents the results of a study focused on assessing the consequences (actual and expected) of applying disruptive technologies developed in key digital economy segments (such as artificial intelligence (AI), big data, the internet of things, blockchain) in conventional banking professions related to the support of basic banking operations (the so-called back office). The analysis of changing requirements for workers and their competences took into account companies' current level of technological development (the application of various products and services, including pilot ones as well as the current demand for specific skills and competences), and the probability of various responsibilities being substituted by automated solutions in the next several years. It was concluded that professions may evolve at the same companies at different rates and technologies' impact upon various segments of banks' operations was sufficiently varied, which made managing human capital a much more challenging task.

Literature Review

Accelerated science and technology progress, along with growing uncertainty, dictate the need to constantly improve approaches to analyzing skills requirements to quickly meet the changing needs of the economy. The proliferation of AI technologies and products such as deep machine learning, natural language processing, computer vision, biometric authentication, smart agents, and personal assistants prompted the emergence of numerous studies analyzing the role of technological breakthroughs in changing the professional structure of the workforce. Among other things it was also caused by the rate of technological change: the time between the emergence of a technology and its mass proliferation is getting much shorter. Futurists discuss the probable arrival of a technological singularity – a hypothetical point in time when S&T progress becomes so fast and complex humans will be no longer able to comprehend it [*Sandberg*, 2010].

Analyzing the substitution of human labor by machines due to the application of robotics or AI technologies, in particular arrival of so-called "technological unemployment" has a special place in labor economics studies [*Kim et al.*, 2017]. The main theoretical aspects of this phenomenon were addressed by classical economists already (see [*Vivarelli*, 2007] for more). One of the more radical forecasts concerned the evolution of professions represented in the US economy [*Frey, Osborne*, 2017]. According to the authors' estimates, technologies will develop so rapidly that in ten years' time up to 50% of workers will be pushed out of the labor market. The widening of the gap between highly- and lowly-skilled workers is predicted. Frey and Osborne's methodology was also applied in a number of other country-specific studies. For example, an analysis of computer technologies' impact on the Japanese labor market indicated a 55% probability of automation [*David*, 2017], while in the OECD countries the relevant figures varied: in Korea the share of potentially automated jobs was 6%, and in Austria this figure was as high as 12% [*Arntz et al.*, 2016]. These differences may reflect not just the level of investments in technological development, but also different levels of education, and different job structures in various countries. A number of studies in this area were criticized for not taking into account the diverse nature of occupation-specific responsibilities and tasks (they can be routine or creative, requiring the ability to deal with non-standard situations). Also, if technolo-

gies' impact on the labor market is analyzed not in broad terms such as professions or occupations, but on the level of specific jobs, it turns out that only 18.2% of workers may be facing the threat of automation. The reason is that an average worker, regardless of their profession, performs numerous tasks that cannot be algorithmized, such as planning, problem solving, presentation, etc. [*Arntz et al.,* 2017].

Also worthy of note are the studies by McKinsey and Boston Consulting Group (BCG) based on the US O*NET professions database data: according to them, at least 30% of professional responsibilities can be automated at the current level of technological development, while the number of working hours for employees whose professions will not disappear by 2027 due to the application of AI in the banking sector would drop by 29% [*McKinsey Global Institute*, 2017; *BCG*, 2018].

Despite the abundance of approaches, and the extensive critique [*Ahmad, Blaug,* 1973, *Colclough*, 1990, *Psacharopoulos*, 1991], almost all attempts to predict national-level demand for skills are based on the so-called "manpower requirements approach" (MRA) [*Hopkins*, 2002]. In a number of variations it was applied in developed and developing countries alike, for example, in the US, the UK, Germany, the Netherlands, Italy, the Czech Republic, and France [*Wong et al,* 2004]. The MRA is a top-down approach: it is based on the assumption that increased output in an industry will lead to proportional growth of demand for all kinds of skills the industry requires [*Williems*, 1998]. The MRA's basic premise, and a major aspect of its criticisms is that workers do not change their activities. According to the basic methodology, "supply of workers specializing in other professions, even with similar skill sets" is unimportant for estimating possible supply/demand imbalances in a particular profession [*El Achkar*, 2010]. At the same time, many researchers stress that such forecasts are based on the erroneous belief that the amount of labor in the economy is set, while it has been empirically proved that increased productivity leads to economic agents' increased income, which in turn results in increased consumer and investment demand – which cannot be met without involving additional labor [*Krugman*, 2003; *Sala*, 2011; *Walker*, 2007]. Also, the approach under consideration does not pay sufficient attention to assessing technology's impact upon the nature and content of work in the scope of specific professions.

Empirical studies in labor economics suggest that the current technological development leads not so much to the elimination as to the modernization of jobs [*Kapeliushnikov*, 2017]. Technological potential is frequently overestimated, while infrastructural, economic, regulatory, and ethic barriers hindering the dissemination of technologies are ignored. At the current stage, technology allows one to accomplish only a limited set of objectives, such as image, voice, and other biometric data recognition; assessing the probability of bankruptcy; analyzing data collected by various devices; predicting hardware faults, and so on. (weak artificial intelligence). Existing systems are not self-aware and do not have the ability to change themselves (strong artificial intelligence) [*Bringsjord, Govindarajulu*, 2018]. The problem of "interpretable artificial intelligence" has not been solved either. Automated systems cannot give feedback and explain the logic of making particular decisions to users, which is critical in areas such as healthcare, national security, and international law [*Brynjolfsson, Mitchell*, 2017; *Gunning*, 2017].

Thus, keeping in mind the limitations, in the near future technological development will probably contribute to carrying out specific job responsibilities more efficiently, rather than fully substituting workers. A shift from routine physical and cognitive operations (which in all probability will be carried out by machines and algorithms) to non-routine ones is expected [*OECD*, 2017].

The digitalization of the financial services industry, along with the growth of the mobile banking segment and the fintech revolution are turning into important drivers for changing skill and competency requirements in the financial sector. The digitalization of key processes at banks allows one to cut costs and improve client experience. A growing number of banks' clients are willing to be served remotely. This is prompted by increased mobile internet usage, more convenient mobile application interfaces, the proliferation of contactless payments, and the growing number of banking products available online. Leading financial organizations are trying to turn into "high-tech companies with a banking license" by implementing their digital transformation strategies. A PricewaterhouseCoopers (PwC) survey showed that in 2017 consumers were quite comfortable with the "digital multichannel" model, i.e., they did not prefer any single channel for interacting with their banks (an internet browser or a mobile application). A similar survey conducted in 2018 indicated that a significant proportion of clients were switching to exclusively mobile banking [*PwC*, 2018]. Therefore, it becomes increasingly relevant not only to optimize bank branches' personnel, but also organize back office operations as efficiently as possible.

Methodology

Over the course of this study we used various quantitative and qualitative techniques including text mining, case studies, and expert interviews. To analyze the current state of the subject area and identify major skill and competency demand

trends, the semantic analysis of academic papers and publications in industry-specific media on the future of the labor market was conducted, along with vacancies published on Russian and international websites such as job vacancy aggregators using the iFORA Intelligent Data Analytics System designed by the HSE Institute for Statistical Studies and Economics of Knowledge [*Bakhtin* et al., 2017; *Gokhberg* et al., 2017]. Additionally, a collection of more than a hundred case studies was assembled from open sources, reflecting the practices of applying technological solutions in selected areas by banking and other organizations. The case studies were analyzed in terms of full or partial substitution of "classic" banking professions.

To obtain and generalize expert opinions, 60 in-depth interviews were conducted with representatives of the relevant professions and HR departments at the top five Russian financial organizations – experts in selected technology domains and corporate education. An expert interview guide was used, comprising 22 questions about the digital transformation of financial companies, the application of advanced technological solutions, staff training and retraining, future prospects for the banking sector's job market (including potential for automating the work), professions that were becoming obsolete, and new skill and competency requirements.

A situation was modeled in the course of the study when banking organizations applied all breakthrough technological solutions available in the middle of 2018 in areas such as AI, big data, the internet of things, and blockchain. Organizations' previous experience in applying digital products and services was taken into account when analyzing changing requirements for workers and their competences, along with the probability of certain professional responsibilities being substituted by automated solutions in the next few years. This should prompt companies' skill requirements to match their new objectives and the need to either cut personnel, hire new professionals, or retrain the existing workers.

Thirty back office professions were selected for the purposes of the study: positions that did not involve serving the financial organization's clients or partners directly. The choice was due to back office processes' suitability for being substituted by algorithmized solutions given their supportive functionality in relation to front office ones, and the relatively uncomplicated (in cognitive terms) nature of many relevant professions (such as supporting and processing business deals, administration, calculations, managerial accounting, bookkeeping, etc.) [*Anagnoste*, 2017]. Between three and five main responsibilities (functions) were identified for each profession. Open-source data was used for this purpose such as vacancies advertised on major Russian job aggregator websites (such as hh.ru, career.ru, finexecutive.com). Having compared the currently available technological solutions with the nature of back office workers' common responsibilities, conclusions were made regarding the potential for their automation, demand for new skills, and need to extend the range of competences.

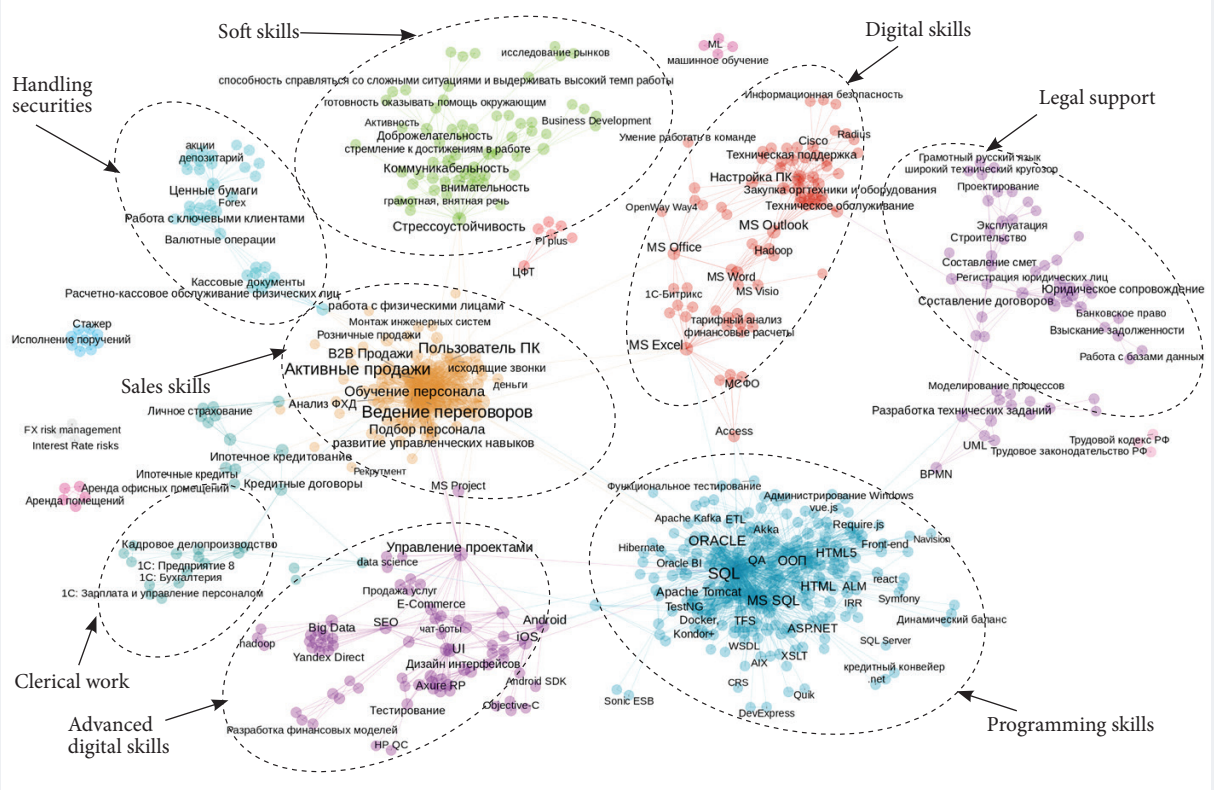
Results

About 18,000 job vacancy descriptions published by top 15 Russian financial sector organizations in September-December 2018 found in the aforementioned open sources were processed in the course of the iFORA analysis using natural language processing and machine learning techniques. The text mining process comprised five main stages: primary natural language processing, syntactic-semantic analysis, subject modeling, structuring (clustering), and the identification of semantic patterns. All meaningful terms were automatically extracted from the texts, and then vector representations of the terms and documents were built by assessing similarity (proximity) of their meanings. Subsequent statistical analysis and data clustering allowed for projecting a multidimensional model of the required competencies landscape into a two-dimensional semantic map illustrating the current demand for competences and skills (Figure 1).

This map shows that even now employers in the financial sector are largely interested in jobseekers' digital skills, such as knowledge of programming languages and specific features of using them in the banking sector; experience with banking software; search optimization skills, etc. Sales skills are still in demand, including in the B2B segment, along with the so-called soft skills – workers' personal characteristics unrelated to specific subject areas, which affect their working style (communication, stress resistance, persistence, etc.). Legal, securities handling, and clerical skills were included in specific clusters.

A detailed analysis of leading international and Russian banking and IT companies' practical experience in applying breakthrough technological solutions in areas such as AI, big data, the internet of things, and blockchain (among them were BBVA, JP Morgan Chase, Goldman Sachs, Credit Suisse, Wells Fargo, Amazon, Apple, Facebook, Google, etc.) allowed to build a comprehensive picture of the current state of technological development, and of technologies' application. On the basis of expert interviews and estimates made over the course of the case studies a "combined effect matrix" was built, demonstrating how and to what extent the main bank back office professions' responsibilities were going to change. It was shown that when banks apply digital technologies, carrying out a significant share of the currently relevant responsibilities would require an extended set of

Figure 1. **Mapping Competency Requirements in the Financial Sector**



Note. The scan was conducted with particular using of the Russian language wording of the keywords. Baseline data is obtained from the HeadHunter jobs service (hh.ru).

Source: HSE ISSEK Smart Big Data Analytics System iFORA.

competences. Some responsibilities were facing the threat of automation, while others were not going to change significantly. The key trend was not the complete substitution or elimination of certain back office professions, but their uneven transformation, to a different extent and at different rates.

A predictive estimate of combined effects of AI, big data, the internet of things, and blockchain technologies on selected banking professions is presented in Table 1.

Strategy analysts' and *business analysts'* responsibilities are the least susceptible to the impact of technologies and poorly suited for substitution since they are high-level activities that require systemic thinking. AI-based products would allow one to partially automate responsibilities related to implementing business strategies and optimizing business processes, but humans will remain responsible for drafting development plans.

The development of automated systems and voice-based biometrics will contribute to the substitution of *call centers'* staff responsible for handling routine (standard) enquiries. Potentially these workers will move on to dealing with non-standard (conflict) issues and serving premium clients (e.g. as "concierges").

Due to the steady improvement of models' accuracy and the reduced decision-making time (occasionally to just a few seconds), the conventional responsibilities of *risk analysts* will be losing relevance. However, the changing of the existing and the emergence of new risks would require constant improvements of the assessment systems and approaches to minimizing their probability. Such workers will be mostly concerned with developing methodologies, since even testing and validating risk models, along with stress testing, would be gradually automated and become machines' responsibility – thus freeing time for human workers to develop more effective risk management tools.

The automation of routine banking processes (processing legal documents, finding debtors, and their assets, etc.) already contributes to freeing a significant amount of *distressed asset specialists'* work time, which can be spent on more complex tasks such as negotiating with borrowers, cessionaries, procurers of non-liquid collateral, and so on. However, these responsibilities will also be substi-

Table. 1. **Estimated Combined Effect of Prospective Technologies on Responsibilities of Banks' Back Office Personnel**

Profession	Responsibilities likely to be replaced by technological solutions	Responsibilities requiring extended competency set	Responsibilities not likely to significantly change
New product analysts	Analysing product sales	Building financial models Designing business models	
Strategy analysts	Analysing financial accounts	Monitoring strategy implementation Analysing top-level business processes	Developing company strategy Agreeing strategies
Underwriters	Collecting information on clients' creditworthiness Analysing collected data	Preparing conclusions	
Auditors	Auditing business processes Preparing audit schedules Monitoring steps taken to remedy violations	Monitoring external audits Designing corrective actions following audits	
Business analysts	Describing business processes Monitoring implementation of proposals	Assessing economic effect of business processes' improvement	Optimising business processes
Brand managers		Designing sets of advertising and marketing actions to improve brand trust and loyalty Forecasting, marketing plans' effectiveness, and managing their implementation Designing brand promotion strategies	
Accountants	Handling paperwork Accounting and bookkeeping Revising documents	Dealing with public authorities	
Designers		Designing marketing project concepts, presentation materials' layouts, logos, etc. Taking part in web design Designing, and creating layouts of marketing materials	
Compliance managers	Identifying, assessing, and monitoring compliance risks	Monitoring and auditing company employees' compliance with policies and procedures Taking steps to prevent and minimise conflict of interest risks Implementing anticorruption measures	
Credit analysts	Comprehensively analysing potential borrowers' creditworthiness Establishing possible lending conditions and deal structures	Drawing up credit reports Structuring loans Communicating with product divisions	
Marketing analysts	Collecting data about users' behaviour Assessing marketing strategies	Supporting analytical data marts Designing prototype data marts for accounting purposes	
Integrated communications managers	Analysing results, preparing progress and final reports about integrated campaigns	Developing integrated media plans, conducting and optimising advertising campaigns Developing integrated media strategies to promote products and services Preparing recommendations to increase efficiency	
Product managers		Forecasting strategies' effectiveness Preparing user stories and user interaction scenarios	Managing product launches Developing product strategies
Tax controllers	Checking tax incentives' applicability, and correctness of tax calculation Preparing audit result reports	Taking part in tax planning Conducting internal tax audits	
Call centre operators	Routing calls depending on the nature of enquiry	Taking steps to address customer requests Taking customer calls Providing information to customers	
Portfolio managers		Taking part in methodology development, classification of tools, assessment and assignment of risk metrics Assessing management results, preparing proposals to improve them in risk/return terms Proposing investment ideas, managing portfolios Designing and implementing investment strategies taking into account risks associated with client profiling, and their specific wishes	

Table 1 continued

Profession	Responsibilities likely to be replaced by technological solutions	Responsibilities requiring extended competency set	Responsibilities not likely to significantly change
Risk analysts	Verifying deals and incidents in line with risk assessment procedures Collecting client data Analysing competitive environment	Building risk models Preparing summary findings and reports on evaluation and analysis results	
Venture communications specialists		Maintaining corporate information publications Building and developing a corporate communication network	Covering corporate events
Collateral specialists	Monitoring current collateral portfolio Preliminary assessment of collateral Creating and maintaining collateral files	Preparing summary findings on collateral assessments	
Treasury specialists	Opening accounts Investing, and attracting cash, securities, and other instruments Processing transaction passports Monitoring and executing operational cash flow		
Macroeconomic research specialists	Providing consulting services	Conducting macroeconomic research, preparing forecasts Financial and economic modelling	
Client operations monitoring specialists	Collecting and analysing client data Monitoring transactions subject to mandatory control, and unusual transactions	Assessing clients' risks	
Distressed asset specialists	Managing and analysing problem asset portfolios Assessing cost-effectiveness of overdue debt collection Monitoring compliance with established collection standards and targets	Reviewing and analysing debtors' financial situation (individual and corporate ones) Developing models for handling problem debts	
Financial institutions specialists	Exchanging business and financial information with partners Concluding and maintaining agreements with financial organisations	Analysing organisations' financial situation Agreeing terms of service, opening correspondent accounts	
Liquidity managers		Managing liquidity Optimising liquidity models Preparing short- and long-term cash flow forecasts	
Financial management specialists		Preparing budget plans for company units Budget control and execution Collecting, processing, and analysing data on units' activities	
Business planning managers	Analysing data, preparing reports	Preparing management reports Preparing business plans for the next year; calculating financial models for strategic areas Preparing medium- and long-term forecasts and plans	
Economists	Assessing potential partners to estimate cooperation prospects	Analysing prospects for providing new kinds of services Calculating costs and payback periods of operations and services	
Legal counsels	Contract work	Providing legal support for company operations Providing legal consulting services Ensuring internal regulatory documents' compliance with legal requirements	
HR managers	– Recruitment	Organising adaptation events Preparing training plans Evaluating workers' performance	Dealing with non-standard issues

Source: compiled by the authors.

tuted by machines. In addition to having general and financial legal knowledge, distressed asset specialists would need to be able to easily handle not only existing databases but also emerging and potential sources of "useful" data and extract, process, and analyze new information including the mastery of big data mining techniques.

The gradual automation of *internal auditors'* "manual" responsibilities (such as preparing audit schedules and proposing corrective action based on audit results for routine operations) will significantly simplify and make their work easier. However, non-standard situations would still require human attention. Also, auditors' responsibilities are established by regulatory authorities and relevant guidance for dealing with specific issues, which would slow down their transformation.

Computerized data processing using cloud technologies, which relieves workers from huge amounts of hard "mechanical" work, leads to reduced demand for such *economists'* and *accountants'* responsibilities as collecting and structuring open-source data for subsequent analysis of the market and economic situations, borrowers' financial and economic activities, and other routine tasks such as conducting standardized calculations, preparing routine reports, control of tax payments and currency operations, monitoring business deals with one's own shares and bonds, and managing short-term liquidity.

In marketing, as in other areas where analytics plays an important role, responsibilities such as collecting information about user behavior, marketing strategy evaluation, and even drafting initial approaches to optimizing client communication channels seem to be best-suited for automation. This would completely relieve *marketing analysts* and *integrated communications managers* from manual analytics, but they will have to acquire basic skills to adjust relevant technologies to meet specific marketing needs and efficiently interpret solutions suggested by automated systems.

Technologies applied in the field of *law and legislation* will allow one to automate such responsibilities as drafting documents, finding necessary information, drawing up model contracts, and advising on common issues. These functions will be transferred to chat bots and law robots. However, they will not be able to handle non-standard issues. The development of blockchain technologies and the introduction of "smart contracts" into daily practice will require changing the competency portfolio. Professionals who not only have legal knowledge but can also work with blockchain software code will be required.

Compliance managers' responsibilities will change in similar ways. Technology will relieve these workers of routine operations and human contribution will be required only in non-standard situations as well as preparing summary opinions about compliance risks.

Conclusions

The results of the study give grounds to predict a significant, qualitative transformation of the skill sets the financial sector's workers will need to have following the application of breakthrough technologies. Semantic analysis of academic publications and the industry media, case studies reflecting best practices for applying such technologies, and information collected over the course of expert interviews at leading Russian financial sector organizations lead to the following conclusions:

Artificial intelligence is a priority for banking operations' digital transformation the world over [*Accenture*, 2018; *Bain&Company*, 2017; *Financial Brand*, 2018; *Financial Times*, 2018]; it radically changes the collection and analysis of information about clients, investment targets, funding sources, and so on. At many banks such technologies help reduce the time required to serve clients, plan call centers' workload, identify questionable transactions, for credit scoring, analysis, predictive modeling of early deposit withdrawal risks, algorithmic trading, and so on. Advanced models have the ability of perception, which allows them to produce impressive results on the pilot project level or when performing routine operations. However, the lack of cognitive abilities makes the full substitution of human intelligence with machines impossible.

Big data analytics is turning into a key competence, defining banks' future competitiveness, making the mass personalization of services possible and accomplishing most of banks' objectives (such as predicting client behavior, optimizing product lines, assessing default risks, etc.).

The internet of things can be applied in all areas where there is a need for remote monitoring of various objects' state and to collect data for predictive analytics, such as production facilities (smart production), retail, healthcare, urban planning and logistics (smart cities, smart transport, smart parking lots), and construction (smart homes). The internet of things allows banks to move to a new level of understanding their clients' needs through collecting and analyzing additional data about their behavior and preferences.

The adoption of blockchain systems in the banking sector, trade financing, logistics, by public authorities and in other areas will eliminate the need to verify, duplicate, and backup data. This, in turn, might lead to the disappearance or transformation of "intermediary" professions related to data checking and verification, such as auditors, notaries, factoring and credit history specialists, and others. So far blockchain remains at the experi-

mental stage with a number of issues (first of all regulatory ones) remaining unresolved. However, numerous financial sector companies, retailers, and transport and logistics operators are actively testing projects based on distributed registry technologies, thus creating and promoting demand for blockchain specialists.

Workers performing all kinds of banking responsibilities will have to work in a high-tech environment and deal with high-level tasks. This primarily implies developing relevant methodologies, modeling, and decision-making based on advanced analytics.

In the future workers will need to constantly extend and "reconfigure" their skill set (competency portfolio) to match the newly emerging responsibilities. Therefore, various soft skills are becoming particularly important, which allow professionals to adapt to changing markets and technologies.

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Coworking Spaces: Windows to the Future of Work?

Changes in the Organizational Model of Work and the Attitudes of the Younger Generation

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Abstract

This paper analyzes how the organization of work has changed since the 1990s including the emergence of digital forms of employment. Following the evolution of work over the course of the 20th century and the start of the 21st, this paper discusses the developments in three periods: the postwar industrialization, the era of automation and digitalization, and, finally, the rise of the virtual economy. Each of these periods correspond with a certain model of production: Fordism, Toyotism, and Uberizm (or Waymoism, named for Google's Waymo project), which each forms a certain organization model of work (process management, project management, and joint or cooperative action management) and requires different sets of skills. During the discussion of the evolution of work organization, including its geographical and temporal aspects, how attitudes of individuals towards work have changed over time is regarded.

Finally, the concept of coworking is analyzed as the cultural foundation for virtual work. Due to the continuing nature of this research, this article presents only the initial results. Therefore citations from one selected – out of 14 conducted – in-depth interviews with managers of co-working spaces are presented to illustrate the first outcomes.

Keywords: organization of work; digitalization; virtual work; skills; work attitudes; coworking; fordism; toyotism, post-fordism; uberizm; waymoism

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Introduction

"How will we work in the future?" was a question I posed during a seminar discussion about digitalization and the future of work. And I received nearly identical answers from different independent groups of students studying sociology at a German university: "We will not 'work' in the future … what humans in the future society will do, is to engage in 'meaningful activities' – 'work' will be done mostly by machines, robots, computers, and algorithms!"

This is a very optimistic scenario that oversimplifies the complex discussion about how the processes of digitalization – automation, informatization, and transformation [*Brynjolfsson, McAffee,* 2014; *Hirsch-Kreinsen,* 2016; *Zuboff,* 1988] will alter the types of work and workload of humans in the near future. However, it does demonstrate a very important aspect of the discourse about the future of work. It shows that the phrase "work" in the eyes of the Generation Z – the "digital natives" [*Tapscott,* 1998] – is a phrase and concept of the past. For the younger generation, the word "work" is related to a way of life they reject. It embodies a social order that differentiates sharply between working and leisure time and where workplaces are clearly delineated from private places. This encompasses a paradigm where "to work" means to act in a rational goal-oriented, and hierarchical manner, while the private and family environment are areas where one can act in a more emotional and cooperative manner. This is a way of life where activities with social esteem are related just to paid work embedded in a hierarchical organization.

What I observed in my seminars is that the younger generation prefers the phrase "engagement in meaningful activity" instead of the word "work". This indicates a change in individual and social attitudes. It is this change in attitudes that I want to discuss and explain using the analysis presented in this paper.

This paper focuses on the changes in the organization of work since the 1990s in the context of the proceeding digitalization process. I begin this paper by taking a look at the history of modern human work in the 20th century. While doing this, I want to point out the main criteria used to differentiate between the organization of work and employment in an analog versus digital and virtual environment. Finally I use the phenomenon of coworking to discuss one vision of the future of work.

The Three Periods of Economic Developments in Postwar Western Europe

The organization of work over the course of the 20th century can be divided into three periods of economic development in Western Europe: postwar industrialization between 1949 and the late 1970s, automation and digitalization between the 1980s and the late 2000s, and the virtual economy starting in the early 2010s. For each of these periods I identify a characteristic model for the organization of work and the essential skill set required for those operating in each particular context. Each period has a characteristic production model, which frames the organization of work and the social landscape (see Table 1).

The production model of the Fordism and Toyotism has been studied in greater detail in the past [*Piore, Sabel,* 1984; *Fujita, Hill,* 1995; *Wood,* 1991; *Bell,* 1999]. So for my short study I choose the automotive industry as reference to obtain a clear picture of the differences between these production models in the three selected periods. The automotive sector was a leading sector in the 20th century and remains so at the beginning of 21st century. The search for the best solution for individual mobility in modern interconnected societies has always produced innovative concepts and structures that calls for improvements in other sectors and areas of social life. The models of the three selected periods can differentiated into the following:

- *Fordism*: the production system of the postwar industrial period where the mass production of cars was an economically successful concept and the Ford-inspired model was a leading organizational concept [*Forgacs,* 1988; *Piore, Sabel,* 1984];
- *Toyotism or Post-Fordism*: a period when the diversified production of high-quality cars became the new key production model that was first implemented in Japan and attained economic success and formed a more flexible and more flat organizational structure [*Wood,* 1991; *Fujita, Hill,* 1995];
- *Uberism or Waymoism*: the newest system based on virtual value chains and the idea of the sharing or platform economy which revolutionized production structure and consumption. This shift has ramifications beyond the automotive sector. The virtual economy allows for the joint use of goods for personal and commercial purposes without guaranteeing ownership rights (for example, cars in the case of individual mobility as the service), thanks to the constant access to these goods by virtual systems. Uber implemented this business model to offer private mobility as a service enabled by a permanent virtual reachable mediation platform [*Stampfl,* 2016]. Waymo went a step further in December 2018 by offering a taxi service with driverless cars supported by a virtual app service [*Krafcik,* 2018; *Laris,* 2018]. This new business model combines the new technology of autonomous driving with a sharing economy business concept for individual mobility. So, what we actually can observe is a reorganization process of the traditional industry production system to a total service-focused value creation system addressing the consumer community acting in a virtual world.

On the basis of this short study of the production model in the three economic periods I further discuss in detail how these production models influence the organization of work and the skills necessary for the

working population. For this discussion I raise the following questions: What does the change from one model to the next mean for the organization of work and skill requirements? How strongly does the change of the model affect the social context as well as the attitudes of the individuals working and living within an economic period?

The Organization of Work in the 20th and Start of 21st Century

Process Management: the Organizational Model in the Postwar Industrial Period

In the postwar period the production sector was the main source of value creation and employed the largest share of the workforce. Henry Ford (1928) developed the idea of the one large vertically integrated organization at one location in order to optimize the mass production of standardized goods by product-specific machines operated by semi-skilled manual workers [*Jessop,* 1992]. The main goal of that kind of organization was to exploit economies of scale by using a network of large assembly lines and modern machines. Mass production and consumption led to a rise in prosperity in Western societies until the 1970s. In this time investments in machinery and modern process management secured competitive advantages. The focus of expanding the production system and economic activities remained very local. Even global companies had locally based production. Globalization just meant building a new manufacturing location at another place in the world with the latest know how and technology. Specialization only took place as the production of different products at one location or another occurred [*Fujita, Hill,* 1995].

Looking further to the organization of work within the larger enterprises in the production sector in the postwar industrial period, one see how the vertically integrated companies generated a special kind of organization of labor based on the idea of economics of scale. Process management tools were adapted from the toolbox of Taylorism and emphasize the concept of standardization and division of labor by dividing the tasks into very small working units to optimize the work flow within a hierarchical work structure. The hierarchical structure was built upon the strong differentiation between unskilled and semi-skilled manual workers as well as highly qualified professionals and managers forming the group of wage and salary earners. Firms required both a broad base of unskilled and semi-skilled workers and a smaller group of professionals in the leadership and expert positions.

The further division of labor and application of other Taylorism tools together with political and institutional restrictions of postwar production relations led to the deep segmentation of labor in the United States and Western Europe [*Doiringer, Piore,* 1972; *Lutz, Sengenberger,* 1974]. However, the institutional environment [*Hall, Soskice,* 2001] was built upon the principles of paid labor on a long-term basis. One of the consequences of such an arrangement with production institutions was the sharp division between work time and free time, workplace and personal space as a result of postwar social and political achievements. This concerns the main type of production relationship, namely work contracts and labor legislation that protects the rights of workers. Such an environment was the product of increased stability, security, and consistent growth of well-being.

Project Management: the Organizational Model in the Automation and Digitalization era

With the advent of the third industrial revolution in the late 1980s, the aforementioned postwar production as well as work organization model began to shift. Following the logic of Bell [*Bell,* 1999] this shift was caused and formed by four technological innovations: the rise of electronically controlled systems; the miniaturization of electronic components; the digitalization of information; and the development of user friendly software. These changes pushed large, vertically integrated companies to reorganize their production systems.

The concepts of modularization and fragmentation played a critical role in the reorganization of production [*Schilling*, 2000], which became popular in Western Europe in the 1990s and were based on the experience of Japan in 1980s. Ohno Taiichi [*Taiichi,* 1988] developed a new production system that took advantage of the new opportunities offered by automation and digitalization. Such new systems were used in a very innovative way in order to shorten the production cycle and better meet the demands of the consumer. The modularization and fragmentation of the vertical value chains both inside and outside of the firm allowed for expanding the assortment of products, improving their quality, and shortening the production cycle in line with just-in-time production management (JIT). The modularization of the value chain also allowed for overcoming the limitations of large vertically integrated production systems and strict organizational hierarchies, facilitating the discovery of the innovative potential of workers, both those employed in manufacturing and in the services sector.

Lying at the basis of the Japanese automotive industry since the 1960s, the base concept of Toyotism [*Fujita, Hill,* 1995] gained increasing amounts of attention in the 1990s and transformed the Western model of work organization. Toyota shifted focus from mass production and economies of scale to a diversified, small-scale launch of high-quality products [*Kern, Schumann,* 1984] and more flexible adaption to the needs of different consumer groups. This concept focused on time as a factor for gaining a competitive advantage on the market. Competitive advantages could be mainly reached during this period by developing and producing diversified, innovative products and services that better meet the demand of the consumer than its com-

Table 1. **A Comparison of the Organization of Work and Wider Social Contexts during the Three Different Economic Periods in the 20th Century and the Beginning of the 21st Century**

Periods of Economic Development	Postwar Industrialization between 1949 and the Late 1970s	Automation and Digitalization between the Late 1980s and the Late 2000s	Virtual Economy since the Start of the 2010s
Organization of Work			
Work Model	**Process Management (Taylorism/ Scientific Management Tools)** • standardization and division of labor • process optimization and control • division of manual and mental work; unskilled, skilled, and highly skilled work • hierarchical work organization	**Project Management (Total Quality Management Tools)** • reintegration of tasks • focus on intrinsic work motivation • self-/cost-responsible management • skill-diversified integrated teams • flat hierarchy	**Cooperative Action Management (Scrum Methodology / Coworking)** • project-based cooperative action • activating self-realization • self-organized/self-responsible teams • temporary work cooperation • matrix organization of work
Dominant Form of Work	production work	service work	knowledge work (digital work/ virtual project work)
Essential Skill Requirements	manual skills; professional skills	technical and professional skills; life-long-learning and project management skills	skills involving technology use, project management, self-realization, and multicultural management
Patterns of Work in Space and Time			
Localization of Work	centralized company /company establishments	local industrial districts/global company networks (analog)	virtual company network
Chronological Structure of Work Processes	working time (regular 8-10 hours); breaks; leisure time	self-regulated working time	blurring boundaries between working and personal time
Broader Organizational Context			
Production System (Automotive Industry as a Leading Model)	**Fordism** • mass production (economies of scale) • standardized goods • product-specific technology • integrating all value chain processes into one organization (vertical integration) • urban hierarchical structure: • control centers in the periphery; • general corporate offices in major national and international cities	**Toyotism (Post-Fordism)** • diversified production of high-quality products • flexible specialized production • just in time production (JIT) • lean organization and outsourcing • close and cooperative contact between • parent firms and subcontractors spacially • organized in industrial districts	**Uberism/ Waymoism** • concept of jointly consumed services with the help of virtual systems • redefinition of consumer goods (e.g., cars) as services (mobility) on the basis of using a joint action management platform (mediation platform logic) • redefines the position of the producer and mediator, consumer and user, while producing new chains and forms of value creation • matrix organization of cooperative actor network (increasing complexity)
Spatial Orientation of Production Systems	local	global	virtual

Source: author.

petitors. Further the integration of products and services as a selling strategy was another key innovative concept, which used the idea of modularization in the context of marketing. However, the concept of modularization was not just adapted to reorganize the production process in a local context. Companies could also use it to rethink the value chain and reorganize the division of labor on local or international markets. The lean management idea applied to a global context of economic activities and led to the building up of an international network of company structures and the loss of local ties by multinational companies [*Fujita, Hill,* 1995].

The basic idea of modularization reappears in the framework of project management as concerns the organization of labor. In modularized production, the organization of labor is focused on reintegrating production tasks to promote motivation and accountability among employees. Functional specialization within the framework of working groups, either centralized or on a project-by-project basis, independently allocates resources and responsibilities while the division between unskilled, skilled, and highly qualified workers (blue and white collar workers) or managers and subordinates loses meaning. With such transformations, workers begin to take more and more responsibility for the results of their work and increase their productivity. However, this reorganization of labor weakens the hierarchical structure and new instruments of personnel management become necessary. The new management methods focus more on the intrinsic motivation of employees and on self-realization instead of company loyalty as the central element of one's attitude towards work.

The essential skill requirements also changed: demand for manual unskilled and semi-skilled labor declined while occupational skilled or professional skilled workers increased in demand amid the conceptual

transformation of labor and ongoing automation processes. With automation and digitalization, the range of operations requiring highly skilled labor expanded while the unskilled tasks were increasingly replaced by automated technologies. Furthermore, accelerated technological progress in microelectronics and modularized systems and a more globally connected structure required more flexibility from the workforce to adapt and acquire new skills throughout one's career, which gave rise to the concept of life-long learning .

In the1980s and 1990s, concepts for labor organization emerged in Western Europe that expanded opportunities for and the responsibilities of workers in line with post-Fordism. These concepts are based on automation and digitalization processes that followed the ideas of the modularization and fragmentation of the value creation processes. This transformation led to a substantial shift in skill requirements and in the principles of personnel management. The increase in demand for skilled personnel emphasizing self-realization as the key part of work mentality and became a key factor for social differentiation. The content of the work has come to the fore on the basis of its subjectification and opportunities for workers to independently determine which work conditions impact their attitude towards work [*Beck et al.,* 1994].

Cooperative Action Management: the Organizational Model in the Virtual Economy

The virtual revolution that began with the mass use of smartphone technology in the late 2010s has become a serious challenge for the organization of production. Given that this change goes deeper than the aforementioned transformation during the microelectronic revolution, using the automotive industry, one can demonstrate that the entire value chain that existed in the 20th century has been called into question [*Rifkin,* 2014]. The new technological opportunities offered by worldwide internet communication technology in conjunction with the proliferation of smartphones provide constant access to a virtual environment. This virtual space allows for establishing business models that do not require the purchase of expensive and technically complex goods or services thanks to the concept of shared use. The idea is simple: combine the infrastructure for reciving information and placing orders in a virtual space at any time with an analog service and joint use service as well as infrastructure for maintenance and support with physical and virtual access. This concept stipulates that the consumer will no longer become the owner of goods, this ownership will remain the producer or intermediary, who organizes the good's or service's joint use.

Such an approach can revolutionize the basic value chain because it blurs the lines between the roles of producer, consumer, mediator, and user. It challenges the consumer economy as a result of which there is the need for new cooperation between the traditional industry and the providers of analog and virtual services. In the case of Waymo, the official provider of driverless taxis, self-driving technology was developed as well as a virtual app for hailing taxis. In order to make these taxis widely accessible, Waymo as the developer of technology that enables driverless driving must agree on cooperation with traditional auto producers and suppliers of relevant analog services (providing service staff and the maintenance work for the driverless cars), the terms of which are discussed behind closed doors. The results of such talks remain an open question given that it is impossible to say ahead of time how a model of unmanned car sharing will change the usual practice of buying a car. It may be possible however to estimate the upheaval caused in value chains over the course of the 21st century. In the case of Waymo, which operates such a technologically challenging product as unmanned vehicles, it is necessary to build safety infrastructure which does not yet exist. The only way to officially bring unmanned vehicles onto the market is to license unmanned car sharing and create the infrastructure for daily checks with the opportunity for intervention if needed.[1] What we see with this simple example is that the roles of the producer, seller, and intermediary are becoming more diversified and the cooperation network of economic actors will become increasingly more complex .

The novelty behind this business model is the virtual space that offers a broad range of possible applications. It is not limited to consumer goods and services, but allows for the exchange of labor, information, cultural goods, security systems, data evaluation systems, and so on. The digital mediation platform logic [*Stampfl,* 2016] used by Uber and now by Waymo is just one way to open up the virtual space for the economic activities. Another common method is crowdsourcing [*van Delden,* 2016], which uses the virtual space to organize resources and virtual communities. Further, the virtual cloud uses this space as a storage and presentation space. The cloud makes information accessible from everywhere in the world and facilitates the sharing of information and other virtual goods [*Boes et al.,* 2014]. Finally, the internet of things uses the virtual space to coordinate the work of automated technology around the globe.

The virtual space opens up an area where time and space are no longer fixed coordinates for cooperative action. It permits the connection of individuals around the world without personal costs[2]. We are seeing the decoupling of time and space unfold before our eyes [*Giddens,* 1990]. This is a crucial moment for understanding the logic of virtual value chains. The virtual space broadens opportunities for autonomous project management aimed at the search for optimal solutions and coordination of joint activities by inde-

[1] For example, weather conditions can impede the safety of the user and would require the presence of an actual driver.

[2] However, infrastructure is necessary for open and full access to the virtual space.

pendent, geographically dispersed individuals in the short or long term. Goods and services produced in such a joint manner can be exchanged via digital channels and physical products can be distributed through virtual systems of access.

So a question arises about how deeply the virtual space impacts the organization of labor and which new forms of work it stipulates. Before discussing this further, first I want to differentiate between the discussions on the digitalization of labor and the virtual production context, which are often used interchangeably in debates about the future of work.

The digitalization of labor stimulates the further automation of production, which has lately affected not only manual tasks but also knowledge work [*Frey, Osborne,* 2013; *Brynjolfsson, McAffee,* 2014; *Autor,* 2015]. However, if progress in microelectronics and software hardly changed the content of work and production operations as such (sure, applications with big data change, and in some case some functions are completely automated as in the administrative sector), then the development of automation, in particular robotics and artificial intelligence, impact both the content of work and the share of manual tasks within it. Given the great significance of these processes and their role in transforming the production and labor landscape since the 1990s [*Rifkin,* 1995], note that I will further focus on the reorganization of labor as the integration of production activities into the virtual space, when I speak about the organization of work within the virtual economy in this paper.

The virtual space changes such critical aspects of labor organization as it allows the joint activity of workers independent of the geographical and temporal coordinates to which they belong. Professional teams working in the virtual context may create virtual products (apps, texts, multimedia content and so on) and provide services (software customization, business administration and management, graphic design). Work done in the virtual space is mostly knowledge work and evaluated based on results. From the point of view of labor organization, the virtual space allows for more effectively using project management tools than traditional corporate working groups. In this space, it is possible to create temporary interdisciplinary expert groups for the completion of projects, which provides impetus for the creation of new groups to work on subsequent projects.

Working in a virtual context means that individual actors mostly have greater autonomy in defining their own workspace and schedule. However, they also have greater responsibility for the management of the production process and communication within a team or compliance with information policy. The virtual production context raises the necessary requirements for and flexibility of workers concerning their technical literacy, project management skills, ability to adapt to constantly changing conditions and work teams over the course of one's entire professional career.

This produces a paradox in that the expansion of opportunities for cooperative action in an "open space" is accompanied by the need to adapt to extremely short-term relationships and maintain flexibility throughout one's working life to continue to operate in this dynamic field. This same paradox can be observed in the concept of coworking that is applied by a broader community of knowledge worker as a role model for the new form of work.

Coworking can be considered the matrix of a production mentality in an individualized virtual society, which serves to integrate separate (often geographically isolated) creative individuals in a working community and is quite different from the traditional forms of work organization. The philosophy of coworking was born in the context of a business model and type of labor organization, the coworking space, which has spread quite rapidly across Western Europe since 2005.

The history of coworking will be illustrated below by some excerpts from an interview with the manager of one of the first such European coworking spaces founded in 2005. This interview was conducted as part of a recent study addressing the question how coworking spaces influence the socioeconomic development of different, both developing and developed, regions[3].

Are Coworking Spaces a Window into the Future of Work?

Coworking spaces are called the third space [*Bouncken, Reuschel,* 2018], located between the extremes of the classic office provided by the employer and the home office as a workplace for the self-employed. However, coworking is more than just a third space. It unites a whole range of business concepts and a special culture aimed at meeting the needs of flexible, agile, self-responsible, and creative professionals[4].

As the first results of the study show, by now several business models of coworking spaces have been developed, which are aimed at solving the problems of a certain community such as:

(1) the requirements of the start-up community to pool resources and to interconnect actors in a professional network context;

(2) the shortage of cheap offices and workspaces for the creative community in overcrowded cities;

(3) to pool forces to build up regional socioeconomic development projects in structurally weak regions through the provision of spaces for joint activity (for example, for regional business networks,

[3] The project is entitled: Coworking Spaces: A new model of organization, business concept, and work. The publication together with Simon Oertel is in preparation. At present we have conducted 14 interviews with coworking space managers in different local contexts and analyzed quantitative data. We made observations of different coworking spaces over the course of one or two months.

[4] Sometimes they are called digital Bohemians [*Friebe, Lobo,* 2006], since most of the workers in the digital economy and virtual space are self-employed or freelancers (digital nomads if their work involves travel [*Ferriss,* 2011]) .

regional politics, joint social projects, and the professional support of women).

Given the perspective of the user of the coworking space, coworking addresses the following needs:

(a) it meets the needs of those isolated in their home office by integrating them into a professional community and local networks;

(b) it resolves the problem of daily or weekly trips to work and back, thus overcoming the need for an alternative workplace and it provides the opportunity to create working communities in the places of residence of employees.

However, all the different business models and user concepts refer to the coworking culture as they call the new established organization form "coworking space". But what are the basic components of a coworking culture?

Coworking practitioners say that the concept of the culture was born in about 2005 when in a number of large cities of Western Europe and Northern America, "third space offices" began independently appearing. The term "coworking" was coined by Brad Neuberg, who was a programmer and who opened an alternative office center for non-profit cooperation in San Francisco. His concept especially met the requirements of the agile, energetic professionals working in the digital and virtual community.

An analysis of our project interview data offers a deeper look into the now established community. One interview with the coworking manager of a coworking space already founded in 2005 in a Western European city shed light on the basics of coworking culture. The subsequent quotes are taken from this interview to illustrate the cultural concept inherent in the coworking space:

The idea of coworking, which has gained such traction in Western Europe, adapt the culture of 19th century Viennese coffee houses. This history provides a positive image of the third workspace, which was designed primarily for creative workers in the digital economy.

"In principle humans have always worked in coffee houses. What changes here and now, that is the mobile technology and its opportunities though wireless networks, through portable computers."[5]

"Well, the main things here are laptops and creativity. Creativity in the sense that it is work outside of the routine ... Sometimes there is also an element of a unique type of leadership."[6] *(Manager of one of the first coworking spaces in Western Europe)*

A deeper analysis of the interview data shows that the basic concept of coworking offers a new approach to the use of the workplace, which becomes possible thanks to digital technologies and the virtual world.

"In my view, coworking is a culture for the organization of cooperation. It is possible to cooperate in various spaces, not solely the office

And I do have the so-called third spaces in mind, they do fulfil a social aspect, thanks to digitalization they have liberalized work: people can work wherever they please: in coffee shops, restaurants, libraries, lounges of hotels, and lobbies. There are coworking centers even in shopping malls…" [7]

"… but not every culture is suitable for every space. Their corporate culture changes depending on the contingent… There have been several cases when teams were called back to the company's offices… Some people quit their jobs because they weren't ready for that. When you understand that there is no way back, something must be done." [8]

In addition to the reinvention of the workspace, coworking culture also changes the nature of everyday work through interdisciplinary cooperation and the formation of local organizational and virtual structures. At the core of this concept is the design principle: joint project work. At the same time, coworking culture contributes to a rise in tolerance and development of life and work skills in a heterogeneous and complex environment.

"I believe that what we see here and now in the coworking space is the future of work. This here is effectively a pioneering feat, which can be seen in the details." [9]

"…Everything started with the freelancers and startups, which were used to work in projects. And now we see that the project form has become the norm of new work. I would call that a generally positive process. Well, viewed in that light, it was a fortunate, evolutionary development, and today project work

[5] Original Citation in German: "An sich haben Menschen schon immer in Cafés gearbeitet. Was jetzt hier anders ist, ist dieses mobile und technologisch Mögliche durch WLAN-Netze, durch tragbare Laptops".

[6] Original Citation in German: "Na, es ist das Laptop und der Kreative. Und Kreative aber im Sinne von Nichtroutine. (.) auch gewisse Führungsebenen sein. …".

[7] Original Citation in German: "Coworking ist meiner Meinung nach eine Kultur, die das Miteinander von Menschen organisiert. Das kann ich auf verschiedene Räume ausbreiten, das muss aber nicht das Büro sein … Und ich habe die sogenannten dritten Orte, die einen sehr sozialen Aspekt oft erfüllen, wo ich aber durch die Befreiung, Digitalisierung wirkt ja wirklich sehr befreiend auf Arbeitsweisen, hingehe, weil ich selber entscheiden kann, wo ich arbeiten möchte. Und das können die Cafés und Restaurants sein, die Bibliotheken, Lounge eines Hotels, eine Lobby. Es gibt Einkaufszentren mit Coworking Spaces …"

[8] Original Citation in German: "… nicht jede Kultur passt in jeden Raum. Und Räume prägen. Und wer hier reingeht, dessen Unternehmenskultur wird sich ändern. … Und wir haben schon wirklich mehrere Fälle gehabt, wo, wenn Teams zurückgerufen wurden in die Zentrale, (.) einzelne Mitarbeiter gekündigt haben, weil dieser Schritt ihnen nicht mehr möglich war. (I: (Lacht)) Wenn man einmal einen Erkenntnisstand erreicht hat, dann kann man auch nicht zurückgehen. … Und es gibt Leute, die dann auch die Konsequenz haben: Ich gehe nicht mit".

[9] Original Citation in German: "Ich glaube, dass wir im Hier und Jetzt in Coworking Spaces das sehen, was wir als Zukunft der Arbeit verstehen. Es ist quasi hier ein Pioniertum. Und das drückt sich im Kleinen aus".

has become the standard especially in the international context. We see now how something familiar to us for years spreads into other areas and into the traditional work organization: work is not tied to a particular place, there's no need to go to the office, you don't need to work at home, that is the core of coworking. It creates one's own space for work, and now it is trusted work place, trusted flex-time that arrived slowly really in the larger companies and is getting implemented there. Often one is little warry of the situation, of course there are regularities, that are old-fashioned. In principle, the thinking about work has not changed for 160 years. I am not a specialist and never studied this topic, but my feeling is that nothing has changed … but it has to..."[10]

"Conflicts and friction do occur. For example, a start-up of one of our users produced products for vegans, and its owner was himself a vegan. Next to him was a lady on a low carb diet, she ate roasted chicken and salad. In the end, bridges had to be built between them, to help them understand each other. Here it was necessary to learn tolerance, to learn to accept diversity. I believe that that is our advantage over a classic office. Of course, everyone is different, but usually people tend to hire those who are like them, who are close to them. In its turn, the activity of a company determines the profile of its employees so that they as a rule have a lot in common. They all received similar degrees, due to which the company lacks the diversity it seeks. Of course, a law office needs lawyers, yes? Nevertheless it can be interesting for them to converse with representatives of other professions."[11]

Conclusion

Returning to our seminar, we ask the students, what they have in mind when they claim that in the future they would not work, but instead would devote themselves to meaningful activity.

They told us a lot about their attitudes toward work. The term "work" implies for them the performance of standard operations. Recently, this concept has been actively discussed by sociologists and the public, who recognize the fundamental nature of the transformation of work and the environment. Thanks to automation and digitalization, manual labor is increasingly replaced by knowledge work, which leads to an increase in the demand for professional skills and at the same time increases the polarization between those who still perform manual work and those doing knowledge work [*Hirsch-Kreinsen,* 2016]. With the virtualization of the working context over the latest decade, the labor of some workers has lost its connection to concrete organizations or places. The existing institutional format is called into question along with the current production mentality both for individuals and for the general working population.

Further, additional work is no longer a prerequisite for monthly income. It has become a personal, individual matter and is more greatly determined by the personality of the worker than before. What we learned over the course of the presented analysis and the reflection of coworking culture is that in the future, responsibility for oneself in a diversified environment will no longer be the prerogative of those with creative abilities and independent mindsets. "New" concepts of labor have already spread into the traditional working contexts. The further digitalization, automation, and virtualization of the production environment will lead to the erosion of the boundaries between companies and other basic forms of labor organization characteristic of Fordism and post-Fordism. This is accompanied by the rising significance of various forms of mediation and coordination of joint activities by independent actors. First of all, there are traditional forms of mediation like agencies, which provide the services of various specialists and temporary employment services that have spread intensively in the post-Ford era. Further, mediation platforms include the development of new mechanisms for organizing and controlling production activities in the virtual space (clickworking). Finally, coworking centers, innovator houses, and other formats offer independent, responsible working individuals workplaces, access to infrastructure for joint use, and opportunities for participating in professional networks. This, however, is done without the social benefits provided by the traditional employer. .

The rising significance of intermediaries increasingly calls into question the postwar institutional environment based on hired labor at companies and other

[10] Original Citation in German: "die Entwicklung hat einfach etwas früher hier angefangen mit den Freelancern, mit den Startups, die waren Projektarbeit gewöhnt. Und dann sehen wir jetzt, dass Arbeit allgemein in Projekten gedacht wird. Also so gesehen, war es die glückliche, evolutionäre Entwicklung, dass das in Coworking Spaces natürlich früher anfing und jetzt halt zum Standard in der gesamten Arbeitswelt zu sein scheint oder zu werden, vor allem international. Wir sehen Sachen, die für uns seit Jahren selbstverständlich sind, das ortsunabhängige Arbeiten, das Nicht-ins-Büro-Gehen, das Nicht-zu-Hause-Arbeiten, das ist der Kern des Coworking. Es ist ein eigener Ort der Arbeit, der jetzt in Sachen von Vertrauensarbeitsort, Vertrauensarbeitszeit langsam Zugang eigentlich in die Großunternehmen findet und da implementiert werden. Oft fremdelt man noch, weil wir haben natürlich auch Regularien, die sehr alter Prägung sind. Also man kann fast sagen, seit 160 Jahren hat sich der Blick auf Arbeit, (.) und das sage ich als Nichtwissenschaftler, der sich nicht damit beschäftigt, gefühlt nicht verändert."

[11] Original Citation in German: "Wir sehen aber auch die Reibungspunkte. Also wir hatten mal einen Mitarbeiter eines/ Sein Startup hat vegane Produkte hergestellt und er selber war auch Veganer. Und neben ihm war eine Frau auf Low-Carb-Diät, die da Brathähnchen und Salat gegessen hat. Und die beiden mussten wir auch zusammenbringen, dass die sich verstehen, (Lachen beide) weil man lernt hier halt noch Diversität auszuhalten kennen. Das ist, glaube ich, auch der Vorteil gegenüber einem Büro. Da sind zwar natürlich alle Menschen auch unterschiedlich, aber zum einen stellen Personaler gern Menschen ein, die wie sie sind. Das ist fast schon unbewusst. Und zum anderen durch (.) das Aufgabenfeld einer Firma werden oft immer die gleichen Leute eingestellt. Die haben alle das gleiche studiert. (I: Okay.) Ja? Und diese Diversität können Firmen dann/ die wollen das, aber sie können das nicht abbilden, ja? Weil als Rechtsanwaltskanzlei brauche ich Rechtsanwälte (Lacht) natürlich, ja? (Lacht) Und trotzdem kann es interessant für diese Leute sein, andere Impulse aus anderen Branchen zu haben."

organizations. Many elements of this environment, which were once considered important social achievements (legislative protection of workers' rights, an official social security system, the widespread use of industry agreements, etc.) are now perceived in an entirely different way. As demonstrated by debates on deregulation in the 1990s, even politicians focused on social issues consider legislation on the defense of workers' rights and participation in professional unions an obstacle for the functioning of markets, which among other things lead to the legalization of market-based employment forms such as agency and fixed term labor agreements [*Helfen,* 2016]. What we observe now is the further liberalization of the labor market that is driven by accelerated technological processes. This calls to the fore the issue of reintegrating these processes into an institutional structure that combines the advantages of technological progress with social solidarity in a virtual community of intensive work.

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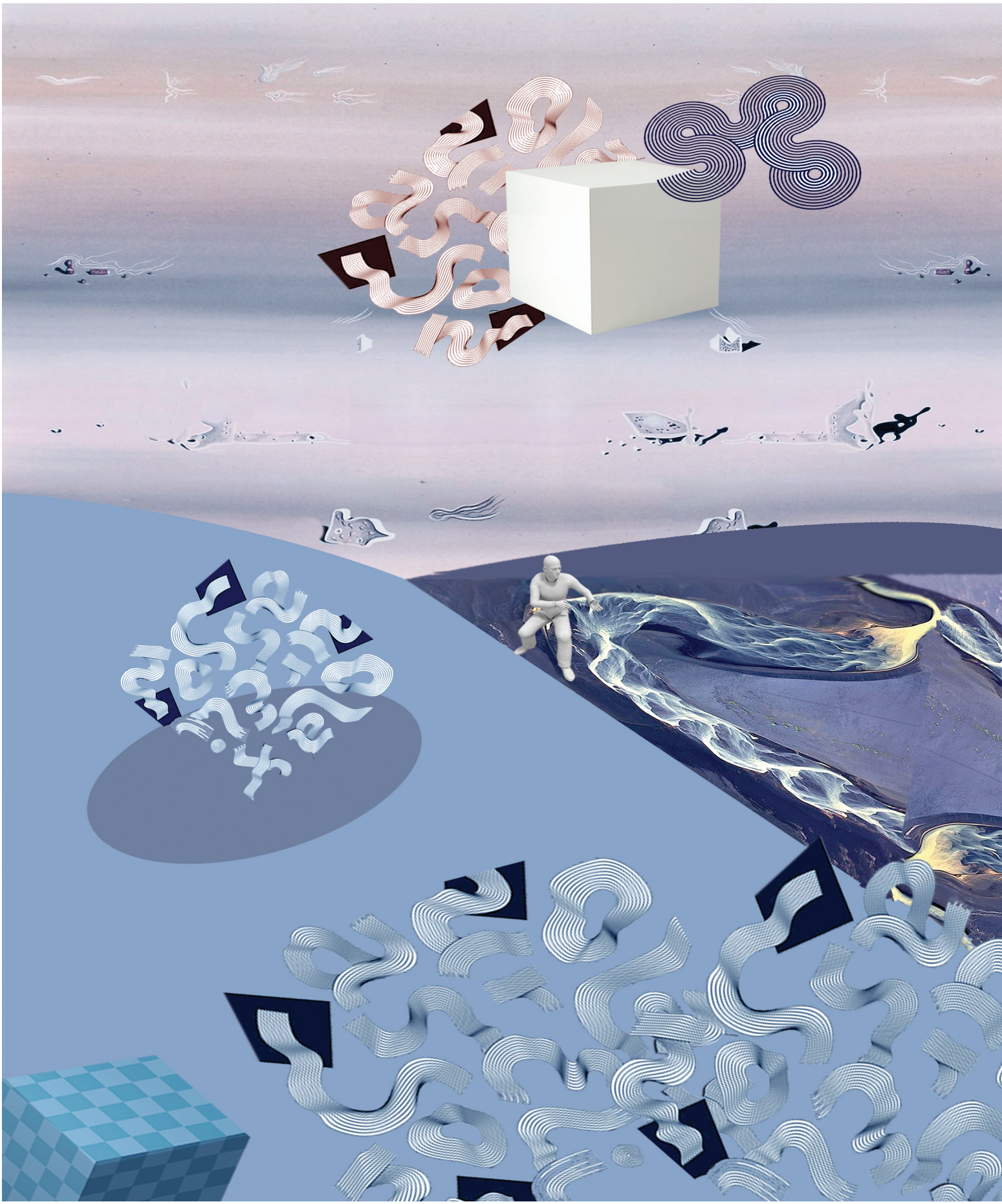
THE DEMAND FOR SKILLS: LOCAL STRATEGIES



Regional Emergence of Start-Ups in Information Technologies: The Role of Knowledge, Skills and Opportunities

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Abstract

We investigate the regional emergence of new information technology start-ups in Germany. The largest share of these start-ups is located in cities or densely populated regions that are well equipped with institutions of higher education and research. The empirical analysis clearly indicates the critical role of industry-specific knowledge plays for new. Hence, strengthening the regional knowledge base should be a key policy that aims at stimulating entrepreneurship in this sector.

Keywords:
innovative start-ups;
information technologies; universities;
regional knowledge

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Over the last several decades information technologies (IT) have emerged as an important sector that has a strong economic impact on the economy and on our lives. It is generally expected that the role of IT industries will become even stronger in the foreseeable future. Regions that host many viable IT firms may benefit from the growing importance of this industry in two ways. First, these firms may grow and directly create employment and wealth. Second, the regional economy may benefit in indirect ways from IT knowledge, for example, through the availability of IT skills and services.

This paper analyzes the territorial aspects of the emergence of new IT firms. Why do some regions have a relatively large number of start-ups while others have virtually none? What is the role of knowledge, skills, and agglomeration economies in the emergence of IT firms? The following sections provide an overview on the potential determinants of IT start-ups at the regional level, introduce the data and report on the spatial distribution of IT start-ups in Germany in the period 2009-2016, and present the results of the empirical analysis. The final section draws conclusions from these findings.

What Determines the Regional Emergence of IT Start-ups?

Based on the literature dealing with regional determinants of entrepreneurial activity, one can identify two groups of factors that may shape the emergence of IT start-ups: knowledge and the availability of resources. According to the knowledge spillover theory of entrepreneurship [*Acs et al.,* 2009; 2013], the knowledge generated by incumbent firms, universities, public research institutes, and others is a key source of business ideas (entrepreneurial opportunities) that may lead to the creation of a start-up. Spatial proximity to such sources of knowledge can be important because new ideas do not flow freely across space but tend to be regionally bounded [*Asheim, Gertler,* 2006; *Boschma,* 2005]. Hence, people located close to such knowledge sources are considerably more likely to absorb and apply the relevant knowledge. Given that founders show a pronounced tendency to locate their firms in close spatial proximity to their residence [*Figueiredo et al.,* 2002; *Dahl, Sorenson,* 2009], start-ups are most likely to emerge in close proximity with the relevant knowledge sources. The availability of resources includes appropriate labor, finance, and other factors that the start-ups need to survive and grow.

In our analysis, we capture the IT-specific knowledge by

- the presence of higher education institutions (HEIs). We distinguish between regular universities and applied sciences universities (*Fachhochschulen*).[1]
- the size of these departments in terms of financial budget.
- the intensity of third-party funding measured as the share of third-party funds in the total budget of the department. Since third-party funds are almost always allocated via some kind of competitive procedure, they can be regarded as an indication of research quality.[2]
- the regional employment shares in IT hardware and software industries.

These measures, particularly the regional employment shares in IT hardware and software, also indicate the availability of qualified personnel.

Agglomeration economies and diseconomies as measured by population density may be another important factor for IT start-ups. Agglomeration economies are made possible by large and productive labor markets where special qualifications are available, financial institutions are present, and there is a rich supply of supportive services [*Helsley, Strange,* 2011]. Agglomeration diseconomies emerge as a result of intense competition for resources that results in comparatively high rents and wages. The density and proximity of people increases the frequency of (face-to-face) interactions among heterogeneous actors, which provides an important basis for knowledge sharing and effective learning (e.g., [*Jacobs,* 1969; *Helsley, Strange,* 2011; *Glaeser, Sacerdote,* 2000; *Storper, Venables, 2004*].

Based on the knowledge spillover theory of entrepreneurship, we expect a positive relationship between the different measures of knowledge and the regional levels of new business formation. The estimated coefficients for these knowledge sources can be regarded as an indication of their relative importance. Is education and research at regular universities more or less important than education and research at the universities of applied sciences? Is it more the sheer presence of the HEIs, their size, or the quality of their research that is more important? We also expect a

[1] Regular universities and universities of applied sciences are different in many respects, including purpose, scope and size, teaching, and research [*Warning,* 2007]. The universities of applied sciences are mainly intended to provide undergraduate education with a focus on transferring theoretical concepts and scientific methods into practical application; these universities do not grant doctoral degrees. Courses are more structured than at regular universities and classes are smaller. Universities of applied sciences tend to have a relatively strong focus on the regional economy. Hence, their partners for R&D cooperation are primarily small and medium sized local firms. In contrast, regular universities have a stronger focus on basic research and have a much wider regional scope. Their cooperative relationships are mainly with larger firms. On average, universities of applied sciences are much smaller in terms of personnel and students than regular universities.

[2] We have no information about the number of students and professors in computer science, which could have been a good alternative indicator.

Table 1. **Overview of Indicators for Regional Determinants of IT Start-up Activity**

Measure	Stands for …
Presence of higher education institutions (HEIs) with a department of computer science Size of computer science departments at local HEIs	IT specific knowledge and entrepreneurial opportunities, as well as the availability of personnel with IT-relevant skills
Intensity of third-party funding of HEI research	Quality of regional research and knowledge
Employment share in IT-hardware Employment share in IT-software	IT specific knowledge and availability of personnel with IT-relevant skills.
Population density	Availability of resources (qualified labor, finance, other services), face to face contact, other agglomeration economies and diseconomies
Source: authors.	

positive relationship between population density and new business formation in IT. Table 1 provides an overview of the different indicators and their interpretation.

Data Description

Our data source for new business formation is the Enterprise Panel of the Center for European Economic Research (*ZEW-Mannheim*). These data are based on information from the largest German credit-rating agency, Creditreform (for a more detailed description see [*Bersch et al.,* 2014]. As with many other data sources on start-ups, these data may not be considered comprehensive given that very small start-ups, such as those that do not have any regular employees ('solo entrepreneurs') are overlooked. However, once a firm is registered, hires employees, requests a bank loan, or conducts reasonable economic activities, even solo entrepreneurs are included in this dataset and information about their activities is gathered beginning with the 'true' date the firm was established. Hence, many solo entrepreneurs are captured along with the correct business founding date. This information is limited to the set-up of a firm's headquarters and does not include the establishment of branches. In our empirical analysis we use these data for the years 2009-2016.

Based on these start-up data, we distinguish between all IT start-ups and the sub groups (1) start-ups in software, hardware & consulting and (2) start-ups in IT retail and leasing. The former group can be further separated into (1a) software, (1b) hardware, and (3) other services. Our main variables of interest are the numbers of new businesses according to the different sectoral definitions.

Data on HEIs come from the German University Statistics of the German Federal Statistical Office, which provides information about every university in Germany[3] and contains, for example, information on whether a HEI has teaching and research facilities in computer sciences. It also provides information on third-party funding and the general financial budget for computer sciences. This allows us to construct a measure for the quality of computer science facilities by comparing the amount of third-party funding to their actual size as captured by the total budget. HEIs are divided into two categories: regular universities and universities of applied sciences. For both types of universities, we count their number, which we include in the analysis as categorical variables. Among the regions hosting a higher education institute with a computer science department the maximum number of regular universities and of universities of applied sciences is two (Table 2). As a control for the size of HEI's computer science departments we also consider the general budget for regular universities and universities of applied sciences in the respective region.[4]

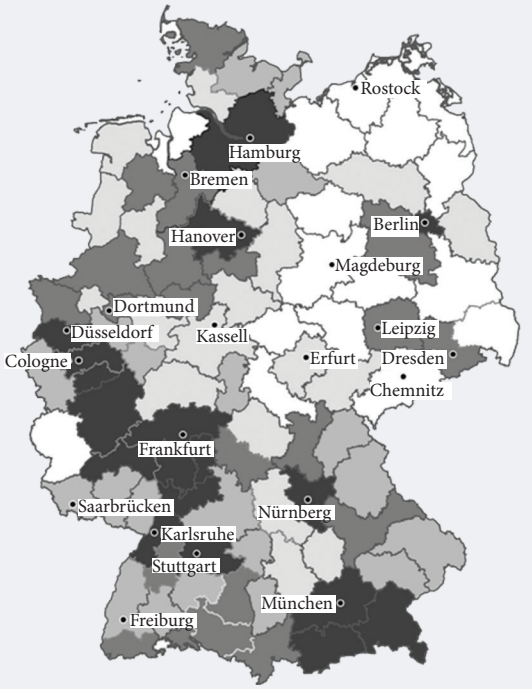
Data on regional specializations were obtained from the Establishment History Panel which is based on German employment statistics. This dataset contains every German establishment that employs at least one person that is obliged to pay social insurance contributions [*Spengler,* 2008]. With this dataset, it is possible to identify regional specializations in IT-related manufacturing and services that we consider in our analysis. More precisely, we used the total number of employees in both IT-related industries and the share of IT-related services within this overall employment as a percentage.

In the empirical assessment we investigate the time period of 2009-2016. Since we are interested in the recent developments of start-up activity, we take the average values for the regional determinants for the period of 2000-2008 to explain the average start-up

[3] https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bildung-Forschung-Kultur/Hochschulen/_inhalt.html. For details, see also [*Fritsch, Aamoucke, 2013].*

[4] We have no information on the number of students and professors in computer science, which would have been a good alternative indicator.

Figure 1. **IT Start-up Rates per 10,000 Working Adults in Germany between 2009 and 2016**



Source: authors.

rate in the different IT sectors in the period 2009-2016. By averaging over these periods, our results are not driven by the impact of the economic crisis in 2008 and we avoid a simultaneity bias.

We use planning regions to create the spatial framework for our empirical analyses. There are 97 German planning regions that represent functionally integrated units comparable to labor-market areas in the United States. The functional economic region of the cities of Hamburg and Bremen comprises also the adjacent planning regions which are merged accordingly.[5] By doing so, we are left with a total of 93 planning regions in Germany, 71 in the area formerly known as West Germany, and 22 in the former East.

The Regional Distribution of IT Start-ups in Germany

Most German IT start-ups are in IT software, other IT services, and IT retail & leasing (see Table 2). Only about 3.7 percent are producing IT hardware. There is great variation in the average yearly number of IT start-ups across regions. Not surprisingly, the number of start-ups in IT industries is much larger in big cities than in rural areas. A simple reason for this phenomenon is that there are more potential founders to be found within the larger workforce of cities. In order to compare the levels of new business formation across regions we calculated start-up rates. The regional start-up rate in IT industries is the average

Table 2. **Summary Statistics**

	Mean	Standard deviation	Minimum	Maximum
Number of IT start-ups				
All	88.323	129.867	4	776
Software, hardware & consulting	68.763	108.723	2	671
Hardware	3.366	4.045	0	23
Software	32.419	54.069	1	368
Other services	33.118	51.557	1	280
Retail & leasing	19.602	23.019	2	109
Number of universities with computer science education & research				
Regular universities	0.677	0.628	0	2
Universities of applied sciences	0.699	0.586	0	2
Size of computer science department				
Regular universities	6 985.305	6 009.895	12.718	29 415.537
Universities of applied sciences	1 875.802	1 455.731	11.657	5 575.184
Third-party funding intensity of computer science education & research				
Regular universities	1 708.215	2 059.328	0	12 725.612
Universities of applied sciences	452.137	1 487.645	0	13 464.313
Other indicators				
Employment share manufacturing IT hardware	4 395.527	7 197.911	145.222	44 668.332
Employment share IT services	0.887	0.147	0.276	0.997
Population density	5.33	0.754	3.887	8.246

Source: authors.

[5] Hamburg is merged with the region of Schleswig-Holstein South and Hamburg-Umland South and Bremen is merged with Bremen-Umland. Berlin could be also merged with adjacent planning regions which implies that the merged area is much larger than the functional economic area of Berlin.

Table 3. **Determinants of IT Start-up Activity in 2009-2016**

	I All IT start-ups	II	III	IV	V	VI IT retail & leasing
		IT Software, Hardware, & Consulting				
		All	IT hardware	IT software	Other IT services	
Number of universities of applied science with computer science education & research						
No university (Yes=0)	Ref	Ref	Ref	Ref	Ref	Ref
One university (Yes=1)	0.619*** (0.182)	0.451** (0.214)	0.249 (0.344)	0.617*** (0.224)	0.313 (0.278)	1.024*** (0.243)
Two universities (Yes=1)	0.913*** (0.247)	0.779*** (0.279)	0.625 (0.417)	0.825*** (0.298)	0.747** (0.347)	1.200*** (0.316)
Number of regular universities with computer science education & research						
No university (Yes=0)	Ref	Ref	Ref	Ref	Ref	Ref
One university (Yes=1)	0.694** (0.277)	0.467 (0.318)	0.614* (0.365)	0.521 (0.356)	0.405 (0.313)	1.410*** (0.268)
Two universities (Yes=1)	0.855*** (0.295)	0.613* (0.330)	0.803** (0.393)	0.689* (0.368)	0.507 (0.333)	1.566*** (0.319)
Size of computer science department at universities						
Regular universities	–0.0298 (0.0498)	–0.00689 (0.0537)	0.0318 (0.0730)	0.00433 (0.0626)	–0.00986 (0.0516)	–0.126** (0.0516)
Universities of applied sciences	–0.0896*** (0.0324)	–0.0561 (0.0375)	–0.0379 (0.0496)	–0.0764* (0.0397)	–0.0444 (0.0479)	–0.177*** (0.0371)
Third-party funding intensity of computer science education & research at universities						
Regular universities	–0.0682 (0.0512)	–0.0655 (0.0547)	–0.126* (0.0673)	–0.0714 (0.0563)	–0.0677 (0.0554)	–0.0544 (0.0503)
Universities of applied sciences	–0.00618 (0.0204)	–0.0199 (0.0240)	–0.0152 (0.0272)	–0.0216 (0.0272)	–0.0176 (0.0263)	0.0314 (0.0208)
Other indicators						
Number of employees in IT manufacturing & services	0.603*** (0.0608)	0.623*** (0.0661)	0.477*** (0.0770)	0.625*** (0.0754)	0.650*** (0.0722)	0.571*** (0.0709)
Employment IT service/Employment IT manufacturing & services	0.552*** (0.121)	0.595*** (0.141)	0.320 (0.218)	0.577*** (0.150)	0.677*** (0.158)	0.451*** (0.138)
Population density	0.245*** (0.0885)	0.231** (0.107)	0.255** (0.102)	0.245** (0.123)	0.226** (0.0992)	0.274*** (0.0650)
Constant	–1.735*** (0.305)	–2.083*** (0.361)	–3.960*** (0.375)	–3.016*** (0.417)	–2.900*** (0.350)	–3.053*** (0.302)
Number of observations	93	93	93	93	93	93
Log likelihood	–388.2	–370	–151.9	–309.7	–309.2	–275.2
Pseudo R-squared	0.239	0.240	0.290	0.259	0.264	0.256

Notes: Negative binomial regressions. The dependent variable is the number of start-ups in the respective industry. Robust standard errors in parentheses. ***: statistically significant at the 1 % level; **: statistically significant at the 5 % level; *: statistically significant at the 10 % level.

Source: authors.

yearly number of new businesses that emerged in the 2009-2016 period divided by the number of people in the regional workforce (in thousands). The regional workforce is the population aged between 18 and 64 years old.

Figure 1 shows that, even when controlling for the size of regional workforce, start-up rates in IT industries tend to be considerably higher in regions with larger cities such as Berlin, Frankfurt, Hamburg, Munich, and Stuttgart than in less densely populated areas. There is a corridor of regions with high levels of new business formation in IT industries along the Rhine from Duesseldorf to Karlsruhe. It is quite notable that IT start-up rates tend to be particularly low in East Germany, the formerly socialist GDR. This observation corresponds to a generally low level of new business formation in this part of the country in the period of analysis.

There may be a number of reasons for higher IT start-up rates in large cities. First, start-ups in IT industries require knowledge that may be regionally bounded, particularly if this knowledge is tacit in nature [*Boschma,* 2005]. Since all larger cities in Germany host at least one HEI that often has special departments for computer science, this knowledge is more likely to be present in these regions than in rural ones. Second, research in computer science may be an important source of entrepreneurial opportunities [*Acs et al.,* 2009; 2013]. As previously mentioned, the founders of new businesses show a pronounced tendency to set up their venture close to their residence. Accordingly, new businesses tend to be locat-

Table 4. **Correlation Matrix**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]
[1] Number of IT start-ups	1														
[2] Number of IT start-ups in software, hardware, & consulting	0.997 (0.000)	1													
[3] Number of IT start-ups in hardware	0.955 (0.000)	0.953 (0.000)	1												
[4] Number of IT start-ups in software	0.987 (0.000)	0.993 (0.000)	0.94 (0.000)	1											
[5] Number of IT start-ups in other services	0.992 (0.000)	0.993 (0.000)	0.944 (0.000)	0.971 (0.000)	1										
[6] Number of IT start-ups in retail & leasing	0.932 (0.000)	0.901 (0.000)	0.886 (0.000)	0.878 (0.000)	0.911 (0.000)	1									
[7] Number of regular universities with computer science education & research	0.484 (0.000)	0.471 (0.000)	0.492 (0.000)	0.472 (0.000)	0.459 (0.000)	0.507 (0.000)	1								
[8] Number of universities of applied sciences with computer science education & research	0.273 (0.008)	0.264 (0.011)	0.308 (0.003)	0.226 (0.030)	0.295 (0.004)	0.292 (0.004)	0.206 (0.048)	1							
[9] Size of computer science department at universities	0.386 (0.000)	0.378 (0.000)	0.397 (0.000)	0.374 (0.000)	0.374 (0.000)	0.39 (0.000)	0.895 (0.000)	0.218 (0.036)	1						
[10] Size of computer science department at universities of applied sciences	0.195 (0.060)	0.184 (0.077)	0.221 (0.033)	0.159 (0.128)	0.204 (0.050)	0.232 (0.025)	0.256 (0.013)	0.901 (0.000)	0.262 (0.011)	1					
[11] Third-party-funding intensity of computer science education & research at universities	0.351 (0.001)	0.34 (0.001)	0.359 (0.000)	0.337 (0.001)	0.335 (0.001)	0.376 (0.000)	0.886 (0.000)	0.213 (0.041)	0.985 (0.000)	0.256 (0.013)	1				
[12] Third-party-funding intensity of computer science education & research at universities of applied sciences	0.171 (0.101)	0.159 (0.128)	0.183 (0.080)	0.139 (0.184)	0.175 (0.094)	0.212 (0.041)	0.193 (0.064)	0.738 (0.000)	0.242 (0.020)	0.833 (0.000)	0.244 (0.018)	1			
[13] Share of employment in manufacturing IT hardware	0.705 (0.000)	0.684 (0.000)	0.709 (0.000)	0.657 (0.000)	0.697 (0.000)	0.748 (0.000)	0.638 (0.000)	0.411 (0.000)	0.636 (0.000)	0.436 (0.000)	0.618 (0.000)	0.377 (0.000)	1		
[14] Share of employment in IT services	0.075 (0.473)	0.072 (0.491)	0.045 (0.671)	0.073 (0.485)	0.073 (0.486)	0.083 (0.429)	0.065 (0.539)	–0.098 (0.349)	0.041 (0.697)	–0.065 (0.535)	0.038 (0.717)	–0.048 (0.646)	–0.104 (0.320)	1	
[15] Population density	0.68 (0.000)	0.656 (0.000)	0.661 (0.000)	0.655 (0.000)	0.645 (0.000)	0.739 (0.000)	0.514 (0.000)	0.25 (0.016)	0.469 (0.000)	0.28 (0.007)	0.471 (0.000)	0.276 (0.007)	0.784 (0.000)	0.091 (0.387)	1

Source: authors.

Table 5. **Robustness Check. Determinants of IT Start-up Activity: University Effects Only**

	I	II	III	IV	V	VI
	All IT start-ups	Startups in IT Software, Hardware, & Consulting				IT retail & leasing
		All	IT hardware	IT software	Other IT services	
Number of universities of applied science with computer science education & research						
No university (Yes=0)	Ref	Ref	Ref	Ref	Ref	Ref
One university (Yes=1)	0.452*** (0.165)	0.459*** (0.173)	0.245 (0.176)	0.492*** (0.177)	0.438** (0.183)	0.425*** (0.158)
Two universities (Yes=1)	1.170*** (0.361)	1.216*** (0.359)	1.014*** (0.341)	1.108*** (0.363)	1.320*** (0.362)	0.989** (0.386)
Number of regular universities with computer science education & research						
No university (Yes=0)	Ref	Ref	Ref	Ref	Ref	Ref
One university (Yes=1)	0.788*** (0.171)	0.827*** (0.180)	0.616*** (0.148)	0.922*** (0.179)	0.762*** (0.194)	0.661*** (0.165)
Two universities (Yes=1)	2.017*** (0.418)	2.103*** (0.453)	1.585*** (0.339)	2.282*** (0.492)	1.972*** (0.422)	1.705*** (0.319)
Other indicators						
Constant	3.306*** (0.130)	2.997*** (0.138)	0.377** (0.152)	2.145*** (0.145)	2.327*** (0.147)	1.997*** (0.127)
Number of observations	93	93	93	93	93	93
Log likelihood	–473	–449.7	–187.5	–379.6	–385.3	–341.4
Pseudo R-squared	0.0726	0.0768	0.124	0.0916	0.0824	0.0774

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.
Source: authors.

ed in geographic proximity of the knowledge sources that are highly concentrated in the larger cities. Third, there are larger volumes of demand in large cities that may be particularly relevant for IT services that require face-to-face contact.

Empirical Analysis

To identify the factors that determine the regional emergence of innovative start-ups, we performed multivariate analyses. Our dependent variable is the average number of innovative start-ups in a region over the 2009-2016 period. We run these models for all IT start-ups as well as for a number of sub-categories: IT software, IT hardware, IT consulting, and IT retail & leasing. Due to the count character of the independent variable, the number of start-ups, we employed a negative binomial estimation technique. In order to avoid any reverse causality issues, all independent variables are yearly averages for the period 2000-2008. While the numbers of regular universities and universities of applied sciences are integer values, all other independent variables are log-transformed.[6]

Table 3 shows the main results. We find significantly positive relationships between the total number of IT start-ups and the number of regular universities as well as universities of applied sciences. According to the estimated coefficients, the effect is more pronounced if a region is hosting two universities of applied sciences or two regular universities. For both types of universities, having two of them is associated with one more IT start-up per 10,000 people in the workforce as compared to regions that do not host a HEI. The effect for hosting at least one university of applied science or a regular university is around 0.5 more start-ups per year as compared to regions without HEIs. In order to test whether the findings for the presence of HEIs are driven by multicollinearity with size measures and other regional variables like population density, we ran models with only the indicators for both types of universities and no other indicator related to size. The results (see Table 4) are rather similar to those of the full model of Table 3.

Somewhat surprisingly the size of universities of applied sciences is negatively related to overall start-up activity in the IT sector while neither the size of computer science departments at regular universities nor the third-party funding intensity are significantly related to IT start-up activity. This result clearly suggests that the size of local computer science departments does not play a role.

The regional number of employees in the IT sector has a positive effect on IT start-up activity. This effect is more pronounced if IT employment is concentrated in IT services. A 10 percent increase in this employ-

[6] There are no negative values. The original variables are scaled up to the extent that the smallest values that are larger than zero assume a positive value after log-transformation. Values that were zero before this transformation are then kept as zeros. More precisely, we multiplied size and third-party funding intensity of computer science education & research by the factor of 10,000.

Table 6. **Robustness check. Determinants of IT Start-up Activity: No Control for Population Density**

	I All IT start-ups	II	III	IV	V	VI IT retail & leasing
		Startups in IT Software, Hardware, & Consulting				
		All	IT hardware	IT software	Other IT services	
Number of universities of applied science with computer science education & research						
No university (Yes=0)	Ref	Ref	Ref	Ref	Ref	Ref
One university (Yes=1)	0.649*** (0.181)	0.474** (0.207)	0.133 (0.327)	0.634*** (0.219)	0.324 (0.261)	1.044*** (0.262)
Two universities (Yes=1)	0.899*** (0.229)	0.758*** (0.253)	0.396 (0.391)	0.778*** (0.263)	0.715** (0.317)	1.152*** (0.337)
Number of regular universities with computer science education & research						
No university (Yes=0)	Ref	Ref	Ref	Ref	Ref	Ref
One university (Yes=1)	0.622** (0.261)	0.391 (0.300)	0.536 (0.368)	0.446 (0.348)	0.333 (0.291)	1.351*** (0.254)
Two universities (Yes=1)	0.896*** (0.262)	0.649** (0.294)	0.778** (0.385)	0.734** (0.340)	0.536* (0.289)	1.612*** (0.298)
Size of computer science department at universities						
Regular universities	–0.0537 (0.0560)	–0.0290 (0.0589)	7.30e-05 (0.0818)	–0.0205 (0.0675)	–0.0331 (0.0570)	–0.156*** (0.0565)
Universities of applied sciences	–0.104*** (0.0338)	–0.0691* (0.0380)	–0.0372 (0.0463)	–0.0899** (0.0401)	–0.0570 (0.0478)	–0.193*** (0.0405)
Third-party funding intensity of computer science education & research at universities						
Regular universities	–0.0373 (0.0500)	–0.0356 (0.0520)	–0.0887 (0.0680)	–0.0398 (0.0530)	–0.0373 (0.0543)	–0.0215 (0.0520)
Universities of applied sciences	0.000488 (0.0194)	–0.0147 (0.0224)	–0.0120 (0.0253)	–0.0159 (0.0254)	–0.0105 (0.0253)	0.0421* (0.0228)
Other indicators						
Number of employees in IT manufacturing & services	0.730*** (0.0409)	0.743*** (0.0442)	0.629*** (0.0573)	0.757*** (0.0520)	0.768*** (0.0474)	0.717*** (0.0515)
Employment in IT services/ Employment in IT manufacturing & services	0.682*** (0.126)	0.713*** (0.144)	0.438* (0.236)	0.703*** (0.149)	0.787*** (0.165)	0.609*** (0.145)
Population density	Нет	Нет	Нет	Нет	Нет	Нет
Constant	–1.319*** (0.271)	–1.695*** (0.297)	–3.630*** (0.388)	–2.633*** (0.346)	–2.522*** (0.319)	–2.614*** (0.334)
Number of observations	93	93	93	93	93	93
Log likelihood	–394.1	–374.5	–154.7	–313.7	–313.1	–280.7
Pseudo R-squared	0.227	0.231	0.278	0.249	0.254	0.242

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.
Source: authors.

ment share is associated with an about 6 percent higher number of overall IT start-ups. Thus, consistent with the knowledge spillover theory of entrepreneurship [*Acs et al.,* 2009; 2013] a high share of employees with industry experience in IT increases the level of new firm formation in that sector. Finally, population density is significantly and positively related to the number of start-ups. A 10 percent higher population density is associated with an about 2.5 percent more IT start-ups. The coefficient estimates for the other variables are relatively similar when population density is excluded from the model (Table 6).

Looking into the IT sub-categories reveals further interesting findings. The effect of HEIs on IT start-up activity seems to be driven by IT software and IT retail & leasing whereas the effect is particularly pronounced for the latter type of IT industries. For IT hardware, there is only a statistically significant effect for regions having two regular universities. For other IT services, the presence of two universities of applied sciences is significant only. In the models that consider only indicators for the presence of HEIs, all indicators are statistically significant (Table 5).

The size and quality of computer science departments do apparently not matter while the number of employees in the IT sector is positively related to the level of start-up activity in all IT sub-categories. The same applies to specialization in IT services. There is one exception namely that the coefficient estimate for the regional employment share in IT services on the number of start-ups in IT hardware is insignificant. This may be an indication that industry experience in IT software is less relevant for the production of IT hardware. Finally, there is a significantly positive

Table 7. **Robustness Check. Determinants of IT Start-up Activity (log-transformed number of start-ups, OLS)**

	I	II	III	IV	V	VI
	All IT start-ups	IT Software, Hardware, & Consulting				IT retail & leasing
		All	IT hardware	IT software	Other IT services	
Number of universities of applied science with computer science education & research						
No university (Yes=0)	Ref	Ref	Ref	Ref	Ref	Ref
One university (Yes=1)	0.748*** (0.180)	0.573*** (0.213)	0.369 (0.325)	0.762*** (0.232)	0.467* (0.245)	1.124*** (0.288)
Two universities (N=2, Yes=1)	1.089*** (0.232)	0.951*** (0.264)	0.729* (0.387)	1.010*** (0.287)	0.972*** (0.295)	1.308*** (0.340)
Number of regular universities with computer science education & research						
No university (Yes=0)	Ref	Ref	Ref	Ref	Ref	Ref
One university (Yes=1)	0.749*** (0.236)	0.547* (0.277)	0.928** (0.450)	0.606* (0.310)	0.482* (0.256)	1.400*** (0.219)
Two universities (N=2, Yes=1)	0.901*** (0.261)	0.668** (0.289)	1.189** (0.480)	0.743** (0.320)	0.579** (0.274)	1.634*** (0.290)
Size of computer science department at universities						
Regular universities	–0.0489 (0.0527)	–0.0292 (0.0553)	–0.0504 (0.0919)	–0.0246 (0.0615)	–0.0362 (0.0546)	–0.143** (0.0603)
Universities of applied sciences	–0.107*** (0.0308)	–0.0710** (0.0352)	–0.0332 (0.0507)	–0.0883** (0.0376)	–0.0645 (0.0414)	–0.190*** (0.0428)
Third-party funding intensity of computer science education & research at universities						
Third-party funding intensity of computer science education & research at universities	–0.0487 (0.0496)	–0.0446 (0.0521)	–0.0683 (0.0852)	–0.0449 (0.0542)	–0.0385 (0.0535)	–0.0332 (0.0532)
Third-party funding intensity of computer science education & research at universities of applied sciences	–0.00323 (0.0199)	–0.0175 (0.0221)	–0.00962 (0.0254)	–0.0221 (0.0245)	–0.0144 (0.0236)	0.0342 (0.0226)
Other indicators						
Number of employees in IT manufacturing & services	0.567*** (0.0591)	0.588*** (0.0630)	0.543*** (0.0777)	0.593*** (0.0677)	0.590*** (0.0670)	0.529*** (0.0690)
Employment in IT services/Employment in IT manufacturing & services	0.510*** (0.124)	0.556*** (0.137)	0.306 (0.260)	0.524*** (0.135)	0.612*** (0.154)	0.380*** (0.142)
Population density	0.288*** (0.0896)	0.275** (0.108)	0.105 (0.131)	0.272** (0.124)	0.298*** (0.0981)	0.306*** (0.0704)
Constant	–1.783*** (0.337)	–2.160*** (0.395)	–3.955*** (0.452)	–3.056*** (0.447)	–2.959*** (0.383)	–3.006*** (0.308)
Number of observations	93	93	93	93	93	93
R-squared	0.901	0.890	0.741	0.872	0.880	0.844

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: authors.

relationship between population density and start-up activity in the different IT sub-categories. The coefficient estimates do not change remarkably when population density is removed from the models (see Table 6).

As a final robustness check, we replicated the results of our baseline models of Table 2 using OLS regression with the log-transformed number of start-ups as an outcome variable. The results are in line with our baseline models. One notable exception is that the effects for HEIs come out more clearly. Furthermore, there is no positive effect for population density in the models on start-up activity in IT hardware (Table 7). Altogether, based on the coefficient estimates and the results of the robustness checks we conclude that regional presence of HEIs plays a more important role than population density. HEIs seem to exert an effect on start-up activity that is independent of population density and the associated agglomeration economies.

Summary and Conclusions

The main results of our empirical analysis of the determinants of regional new business formation in the IT sector can be summarized as follows.

- First, IT start-ups are concentrated in large cities. The propensity of an IT start-up to emerge in a rural area is rather low.
- Second, a main reason for the geographic concentration of new IT businesses is the presence of HEIs with education and research in computer science. HEIs with computer science departments may be important for the qualification of the regional workforce in IT and as a source of

new knowledge that opens up promising entrepreneurial opportunities in this technological field.

- Third, it is not the size of the computer science departments at HEIs nor the quality of the research but more their sheer presence that is important for the number of regional IT start-ups.
- Fourth, there is a significantly positive relationship between the regional employment share in IT services and the number of IT start-ups. This is a further indication of the important role industry-specific knowledge plays in the level of entrepreneurship in a certain sector.
- Fifth, population density and resulting agglomeration economies may be conducive to the regional formation of new IT businesses. The effect of population density as such is, however, much smaller than for the presence of HEIs.

All in all, these results are consistent with the knowledge spillover theory of entrepreneurship [*Acs et al.*, 2009; 2013] that emphasizes the role of knowledge for new business formation. Accordingly, strengthening the regional knowledge base should be a key strategy of any policy that aims at stimulating the number of regional IT start-ups. Since there are good reasons why HEIs in computer sciences are located in larger cities, such high-density regions have a locational advantage in this sector as compared to rural regions.

A limitation of the study is the fact that the data for start-ups do not necessarily cover very small firms such as new businesses that consist of only the founder and have no further employees (solo entrepreneurship). This neglect of micro firms can, however, be also regarded an advantage in the sense that the analysis includes start-ups that may have an effect on the development of the respective region. Future research should complement our findings with a qualitative assessment of location choices of IT founders and the role that local conditions such as the regional knowledge base have for their decision-making and the venture process.

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The Industry 4.0 Induced Agility and New Skills in Clusters

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Abstract

The fourth industrial revolution (Industry 4.0) transformed global value chains by transforming them into adaptive networks of enterprises. To remain competitive, companies need to integrate themselves into these networks, which require increased flexibility in terms of reorganizing business structure and expanding the portfolio of competencies. This article attempts to find ties between the concepts of Industry 4.0 and clusters. This new viewpoint helps one discern the role clusters play in the development of necessary skills as part of this nww context. Spatial proximity provides unique opportunities for such interactions, which cannot be imitated by remote digital technologies. As a result, clusters, while meeting certain requirements, will not lose their relevance in the context of Industry 4.0, but, on the contrary, become its key driver.

Keywords: fourth industrial revolution; Industry 4.0; cluster; networks; global value chains; agility; skills

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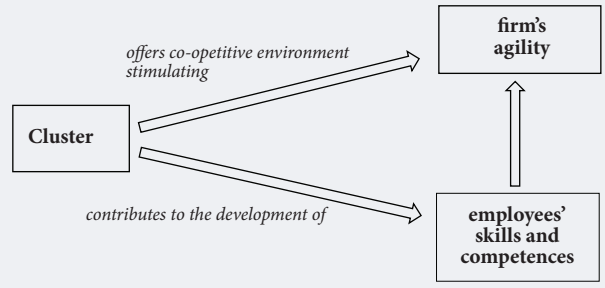
Industry 4.0 or the fourth industrial revolution is sweeping the globe, mainly across developed economies, and is gaining the attention of policymakers, in business circles, and among industry representatives and scholars [*Schuh et al.,* 2014; *Hermann et al.,* 2015]. Researchers who started dealing with this digital transformation agree on the scale and scope of changes that the fourth industrial revolution would cause. The need to respond to the challenges presented by these transformations calls for major modifications of policy plans, industry strategies, business models, production methods, value chain governance, and attractiveness of places [UNCTAD, 2017]. The experts, however, disagree as to whether Industry 4.0 is indeed the fourth revolution or just the next stage of the previous one [*Alcácer et al.,* 2016]. Most available papers deal with technical, engineering, managerial, or strictly business aspects of this profound transformation [*Kagermann et al.,* 2013; *Drath, Horch,* 2014; *Brettel et al.,* 2014; *Lydon,* 2016]. To the best of author's knowledge, the literature linking Industry 4.0 with clusters is almost non-existent [*Götz, Jankowska,* 2017]. A systematic approach to the Industry 4.0 has only been emerging gradually [*Liao et al.,* 2017]. Industry 4.0 is supposed to have a profound impact upon Global Value Chains (GVC) and international production [*Folkerts-Landau, Schneider,* 2016; *Alcácer et al.,* 2016; *Strange, Zucchella,* 2016; UNCTAD, 2017]. It implies a shift towards highly adaptive networks of integrated entities [*Kagermann et al.,* 2013]. In such an environment, companies would be required to display a high level of agility – the ability to orchestrate various activities and competences and swiftly become insiders of certain chains and networks with employees equipped with a new set of critical skills (Figure 1). Clusters, as hybrid form of organization, epitomizing the simultaneous cooperation and competition (coopetition) might offer conducive conditions for the ongoing digital business transformation and help equip employees with the necessary competences and skills (Figure 2) [*Alcácer et al.,* 2016; *Sajdak,* 2014; UNCTAD, 2017; ASTOR, 2017].

Figure 2. **Cluster role in Industry 4.0**

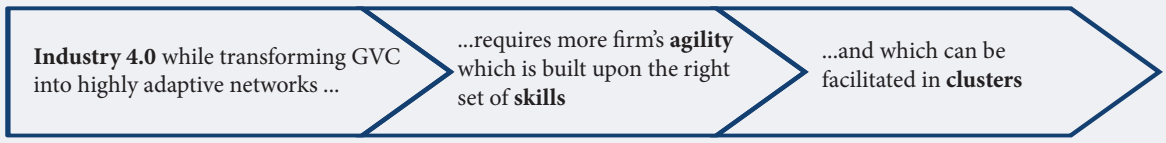


Source: author.

This paper will attempt to shed light on existing relations and advance our understanding of the role of clusters in the realms of digitally transformed production. It identifies the relationship between these two by making the reference to networks, GVCs, and the concept of agility which is derived from a set of specific employees' skills. The paper relies on various sources. Besides the literature review (dominated by IT and industry specific papers[1]), business media and industrial magazines from Poland[2] and abroad[3] as well as insights gathered from experts have been employed[4]. Consultations with selected industry and academic representatives took place in the middle of 2016 in the form of semi-structured phone calls and direct interviews as well as the exchange of emails. The main topics discussed within interviews are presented in Table 1.

The results of these interviews are presented and discussed throughout the paper to corroborate and strengthen the claims made. This manuscript should

Figure 1. **Changes Triggered by the Fourth Industrial Revolution and Their Relation to Clusters**



Source: author.

[1] The researchers only started dealing with the entrepreneurial angles of Industry 4.0

[2] Available in Polish media, the opinions and comments expressed by experts responsible for the digitalization and implementation of Industry 4.0 - R. Grucza, vice chairman REC Global; M. Kaczurba – Enterprise Partner Manager, Microsoft, T. Jadczak, chair in SAP Asseco Poland, R. Krawczyński, Oracle Polska, D. Lis, director in Transition Technologies SA, Poland Solution Center, B. Kamiński, partner in Infovide-Matrix, M. Pawlik – director in BPSC.

[3] Publicly available and quoted opinions of representatives of Siemens, Volkswagen, Baluff, Rec Global, and Mercedes.

[4] Consultations with professors B. Kamiński (Warsaw School of Economics), J. Gracel (ASTOR), B. Woliński (Siemens), Z. Piątek (Przemysl 4.0)

Table 1. **Topics for Interview**

Thematic Category	Questions to Discuss
Factors critical for the development of Industry 4.0 and major challenges	• Technical dimension (quality of bandwidth and network security) • Legal aspects (regulations, standards, norms) • Social aspects (such as the elimination of many professions and high demand for skilled and educated staff) • Main issues raised in the context of Industry 4.0 induced challenges – how will they play out within and among countries?
Competitiveness in light of Industry 4.0	• What is/will be crucial determinant of competitiveness and future international cooperation within the value chains in the face of Industry 4.0? • The alignment of legal aspects (international regulations), the technical solutions (transmission security), or rather the individual capabilities of specific companies - which solutions would become critical factors for their adjustment in the field of Industry 4.0?
Reconfigurations and risks	• Can traditional suppliers and partners be at risk if they cannot keep up with the progress in automation, digitalization? • How can the current business relations be reshaped? • What is the risk of eliminating those who cannot adapt?
Asymmetry and monopolization of benefits	• Do these developments and new business models increase the (over)dependence upon suppliers? • Are there benefits for the leader or pioneer who adapts certain solutions on the basis of a quasi-monopoly («front runner»)?
Accurate capturing of Industry 4.0 advancements*	• How does one approach the exploration of Industry 4.0 progress in an international context?

Note: * — Available data and indicators such as the one on the development of broadband networks, or the use of computers, etc. only suggest the conditions / potential for Industry 4.0, but do not inform about companies' actual capabilities to transform business models.

Source: compiled by the author.

be regarded as explorative study; a conceptual consideration and reflection upon the selected aspects of ongoing digital transformation. It outlines the pattern of relationships between Industry 4.0 and the geographical concentration of activities in the form of a cluster, in particular the advantages it can offer for firms to be agile and employees to possess the right set of skills critical for advancing the digital transformation.

Conceptual Definitions of Industry 4.0 and Clusters

Despite the growing popularity of the fourth industrial revolution there is still a lack of effort to systematically review the state of this wave of digital transformation [*Roblek et al.,* 2016; *Liao et al.,* 2017]. Institutions define the term differently, highlighting selected elements (see Table 2). In general, Industry 4.0 is also depicted as a government-sponsored vision for advanced manufacturing and a strategy for re-industrialization. Industry 4.0 encompasses among other things autonomous advanced robotics, augmented reality, additive manufacturing, artificial intelligence, big data, and cloud computing. Key elements of this transformation can be also summarized as decentralized intelligence, rapid connectivity, context integration in real time, and the autonomous performance of tasks [*Immink,* 2015; Bosch, 2015].

Industry 4.0 constitutes a specific amalgamation of concrete IT solutions, a unique set of engineering, and the combination of computer science with management. The digitalization of traditional industrial sectors thanks to Industry 4.0 leads to the gradual disappearance of borders between plants, branches, firms, or even geographical areas. Whereas scholarly papers

Table 2. **Some Definitions of Industry 4.0**

Organization	Definition	Sources
German Industry Association (Bundesverband der Deutschen Industrie, BDI)	Fourth industrial revolution	[BDI, n.d.]
Germany Trade & Invest (GTI)	A paradigm shift from "centralized" to "decentralized" production and envisages that the product communicates	[GTI, n.d.]
McKinsey	Next phase in the digitization of manufacturing	[*Manyika et al.,* 2016]
SAP	A collective term for technologies and concepts of value chain organization	[SAP, 2017]
European Parliament	A group of rapid transformations	[*Smit et al.,* 2016].

Source: compiled by the author using the mentioned works.

touch mainly upon the technical aspects, the dossiers drafted by international organizations and think-tanks revolve around the expected benefits and challenges this revolution might bring about, there is still little understanding of the spatial dimension of Industry 4.0 and hence, of the role of clusters as providers of a conducive environment for agile firms and skilled workers.

Clusters are spatial hubs of linked companies, specialized suppliers, service providers, and associated institutions in a particular field that are present in a nation or region [*Porter,* 2000]. Despite the popularity in academic as well as policy circles, the cluster concept is sometimes criticized as being too imprecise [*Pedersen,* 2005]. The basic features of clusters are presented in Table 3.

The Digital Transformation of Global Value Chains and Networks

Industry 4.0 stipulates the digital transformation of production, smart dispersed manufacturing, self-optimizing systems, and the digital supply chain in the information-driven cyber-physical environment [*Brettel et al.,* 2014]. It means the organization of production processes based on technology and devices autonomously communicating with each other along the value chain [*Smit et al.,* 2016]. It also heralds a new model of collaboration and incarnates the idea of "connected enterprise" where almost everybody is cooperating with each other along the value chain. Advances in ICT have supported new governance mechanisms in GVCs and shape modern global networks supported by foreign direct investment [*Foster, Graham,* 2016]. Whereas some studies [*Rangan, Sengul,* 2009] argue that ICT adoption facilitates control in outsourcing, thanks to the constant information exchange; others associate ICT with higher in-house production [*Chen, Kamal,* 2016].

New forms of cooperation and competition as well as new solutions with a reduced share of mechanics and hardware in the overall customer value proposition are emerging in the digital era [UNCTAD, 2017; *Mikusz,* 2014]. Particularly, previously isolated business models of the traditional goods-producing industry meld together with those of software businesses. Customer-oriented business models characterized by interactive value creation with users and other external actors as well as innovative processes that are realized in inter-organizational networks are becoming key competitive factors. The powerful consequences of digitization and additive manufacturing entail the transformation of economies of scale into economies of scope, and the production of any object in any place. Interdisciplinary technologies brought by the fourth industrial revolution will create new business models based on manufacturing as a service (MaaS). New technologies enable turning manufacturing companies into service providers as consumers might be interested in simply using the product but not necessarily owning it [*Kumar et al.,* 2016]. Companies can "rent" production capability and capacity as needed without the need for providing the final product. Besides, large companies that can take advantage of their scale and data insights tend to add new business lines, which leads to their expansion and is increasingly blurring the traditional sector boundaries amid the complexity of GVC governance [*Manyika et al.,* 2016]. It can be argued that the fourth industrial revolution not only transforms the architecture and organization of value creation, but it also moves the logic of production from the simple chain of activities adding value to networks and further to platforms of value creation. Clusters might be regarded as the nodes of global production networks or cores on modern industry platforms [*Götz, Jankowska,* 2017].

The aforementioned characteristics and features of modern production systems and digital transformation in fact embody many of the properties of clusters. Intense cooperation in various constellations, sharing know-how, iterative upgrading processes, melting processes, and connecting tasks and yet fragmenting them as well as harnessing available suppliers: all these resemble the attributes of full-fledged clusters with specialized entities collaborating and competing along the value chain, outsourcing certain functions when necessary or merging others when more suitable. The capacity to create and seize value would depend upon building new networks and becoming an insider thereof. The ability to swiftly join existing networks of collaborating entities would therefore be crucial for participating in Industry 4.0 global value chains.

Industry 4.0 epitomizes the business-to-business (B2B) interface of digital transformation [*Hüther,* 2016]. It refers to interactions among firms in a highly-digitalized network functioning in the combined manufacturing-service production. This implies that the production chain binds tightly successive stages thanks to the

Table 3. **Main Features of Clusters**

Definition	• Useful instruments in regional and development policy that epitomize coopetition, create synergies, foster innovativeness and competitiveness [*Njøs et al.,* 2016] • Hybrid forms of long-term contracting and reciprocal trading [*Maskell, Lorenzen,* 2003]
Attractive features [*Porter,* 2000; *Ketels,* 2004; *Brodzicki,* 2005; *Götz,* 2009]	• Superior competitiveness and innovativeness • Conducive knowledge environment stimulating learning • Pecuniary agglomeration economies enhancing effectiveness thus improving profitability • Institutional setting possibly reducing uncertainty and transaction costs

Source: compiled by the author using the mentioned works.

high-quality connectivity that guarantees the availability and fast flow of information. This leads to dense networks. Brettel et al. [*Brettel et al.,* 2014] write that collaborative networks are antecedents for cyber-physical systems (CPSs), which are the backbone of the fourth industrial revolution. Network is conceived as a set of reciprocal, reputational, or customary trust and cooperation-based linkages among actors that coalesces to enable its members to pursue common interests [*Cooke,* 2001, p. 953]. Having the status of "an insider" in relation to a specific business network would become crucial for the firms' existence especially in a highly connected and competitive environment [*Forsgren,* 2016; *Johanson, Vahlne,* 2009].

The permanently changing operating conditions of enterprises have put the processes of shaping the competitive advantage into a new light. Ratajczak-Mrozek [*Ratajczak-Mrozek,* 2010] emphasizes the impact of business networks and their constituents on the competitive advantage of companies on foreign markets. The network approach as a framework for business research has emerged among others because of the technological changes taking place in the B2B market and increased international competition. A business network can be defined as a collection of long-term (formal) and informal (direct and indirect) relationships between two or more entities. No company manages the network or is its "owner", although a single company can take on a strategic position within the network (strategic center). Business networks are paradoxically both stable, durable, and variable as they evolve over time [*Forsgren et al.,* 1995; *Johanson, Mattsson,* 1987]. Variability is due to the emergence and disappearance of old relationships and is induced by the uncertainty of the environment and the need to respond to emerging opportunities and threats. At the same time, however, the networks are stable as the frequent change of co-operators is difficult due to the high costs of the mutual adaptation processes. Solutions made possible by the digital transformation enable the existence of virtual corporations which are in fact the networks of independent organizations that share competencies with the aim of exploiting a business opportunity [*Davidow, Malone,* 1992]. The ability to leverage the competencies of network members so they can accurately react to market needs should result in sustainable advantages [*Christopher,* 2000].

Being an advanced form of network cluster offers various benefits which can be attributed to localized demand and supply linkages, available pools of labor market skills, technical and knowledge spillovers transmitted via different channels [*Overman et al.,* 2001]. According to [*Sorenson,* 2003], clusters are idiosyncratic business networks since whereas firms within traditional networks might be spatially dispersed, firms in clusters operate in a particular location in geographical proximity. This spatial closeness fosters relationships since the frequency of personal contacts can be increased and the social relationships between the actors can be developed. Thanks to the relational proximity, the transfer of knowledge can be facilitated [*Rosenkopf, Almeida,* 2003]. Clusters present in a given geographic area can network with different regional entities – local companies, laboratories or regional authorities – along the broader value chain.

Summing up, clusters as geographic agglomerations of related industries and associated institutions [*Delgado et al.,* 2014; *Marshall,* 1920; *Krugman,* 1991; *Ellison, Glaeser,* 1997] enable intense network-like relationships and serve as a hubs for industries connected through various linkages, such as knowledge exchange, skills upgrading, input factors' provision, demand, and other associated facilitating institutions [*Delgado et al.,* 2014].

New Skills in Digital Transformation

Digitalization can indeed offer various benefits, however, these come with strings attached and hidden traps due to the increased complexity [*Schmidt et al.,* 2015]. It affects the entire supply chain from product design and development, through to management and logistics to final distribution [*Prause,* 2015]. Therefore, it incentivizes firms to rethink existing business models and to figure out new structures. Certain solutions in this respect may be provided by the fractal company with such features as self-similarity, -organization, -optimization, and dynamics [*Warnecke,* 1997]. A fractal company can be also regarded as a multi-agent system, with fractals monitoring its environment, and making decisions based on the received feedback. Such a mechanism resembles those known in clusters.

Until recently, the overriding aim of a firm was to develop and maintain a long-term competitive advantage without which any competitive position of the company becomes very unstable. However, in the subject literature of recent decades, one can find the view that the importance of long-term competitive advantage decreases [*D'Aveni,* 1998]. The terms of hyper-competitive, dynamic, aggressive, and intense competition imply that what really matters is flexibility and the ability to immediately adapt to changing conditions or even the capability of doing this ahead of changes i.e. to strike pre-emptively [*Romanowska,* 2004]. Thus, in a hypercompetitive environment, the lasting competitive advantage is replaced by a series of temporary states of relative superiority [*D'Aveni,* 1998]. This means that companies, instead of trying to maintain their long-standing competitive advantage as long as possible should instead continuously monitor new ways of maintaining a dominant position in networks. This requires certainly agility skills. Morisse and Prigge [*Morisse, Prigge,* 2017] mention organizational agility as an important ability in the context of Industry 4.0.

Industry 4.0 can be defined as changeable, agile, reconfigurable, and virtual production [*Qin et al.,* 2016]. This implies manufacturing systems that are intelligent, integrated, and automated as well as those that

have advanced architecture. It also inevitably leads to changing traditional production relationships among suppliers, producers, and customers as well as the relationship between the human and machine. This poses a severe threat to laggards, i.e., firms struggling to catch up with ongoing digital transformation [*Hessami,* 2017; *Rüßmann et al.,* 2015]. It requires the necessary adjustments from all involved parties and the avoidance of becoming stuck in incremental approaches, forcing suppliers in particular to leverage their technologies [*Rüßmann et al.,* 2015]. Firms, being involved in such a modern chain or network relationships should do the following: define which business model to use to leverage upgraded or new offers; build the necessary technological foundation (tool base for analytics); devise and implement the right organizational structure and its capabilities; and participate in and shape technological standardization. In parallel, firms need to build a scenario-based vision of the long-term industry evolution. Such an approach stresses the long term and predictive attitude, though, the importance of the capability of swift and flexible reactions and adaptations to changing conditions cannot be underestimated.

Under the fourth industrial revolution, firms are seen as repositories of competences, knowledge, and creativity, as sites of invention, innovation, and learning [*Amin, Cohendet,* 2012]. Among the new crucial capabilities that need to be harnessed by firms willing to remain competitive is agility. This complex definition has numerous interpretations. In sum, one can highlight the following basic features of agile companies [*Manyika et al.,* 2016; *Meredith, Francis,* 2000; *Gunasekaran,* 1998; *Sajdak,* 2014]:

- the ability to extract valuable information while working with "big data";
- sensing threats and exploiting market opportunities;
- swift response to change;
- adaptivity to changes;
- openness to new opportunities;
- ability to learn fast;
- decentralization of power, autonomy, and empowerment;
- flexible reconfiguring organizational structure, business processes, tangible and intangible assets;
- swift combining vision and operational management (ambidexterity);
- lean production;
- personalizing offers to customers.

The agility of company must be also regarded first of all as a function of the flexibility and adaptive attitudes of its employees, rather than that of a conducive cluster environment. Industry 4.0 heralds significant challenges for the contemporary labor market. The higher complexity of work would require more flexibility from employees causing simultaneously greater instability. There is a risk of an "hourglass society" with a small and decreasing middle class, the disappearence of medium-salary earners, and growing disparities. Such unequal distribution would obviously affect societies within each country, but it may also play out among countries, where some of them would unfortunately find themselves in this hollowing-out of the middle. In other words, the hourglass society and hollowing-out might play out along global value chains not only within one society. Another risk is the possibility of mass unemployment for some categories of workers, combined with significant shortages of skills in other categories [*Mesnard,* 2016]. Robotization and automatization may result in a situation where the human workforce becomes dispensable, leading to the need for introducing such compensating mechanisms as universal basic income. Despite these challenges, threats, and risks, the consequences of the digital revolution might translate into more jobs in the long run. Analyses by IW Köln indicate that these adjustments would turn out positive for Germany since approximately one third of the firms undergoing digitalization plan to increase employment and only one tenth predict layoffs [*Klös,* 2016]. The outcome of these reshuffles is not yet known. In the specialization scenario, where human labor is steering the CPS, gains and positive employment effects can be expected, in contrast to the robotization scenario, which sees human workers only as the extension of digital systems. The fourth revolution undoubtedly would modify the structure of the labor market and although many jobs would disappear, new ones would be created. This poses a huge challenge for education and training systems and, given the high knowledge input, requires close cooperation between business and academia, which is usually associated with full-fledged clusters.

It is impossible to compile a single comprehensive list of skills needed in the age of Industry 4.0. Different researchers and organizations propose various sets of skills focusing on different issues (see examples in Table 4). Generally, in addition to hard skills, there is rising demand for soft skills that are generic personal skills useful within a wide range of professions, such as the ability to be a team player, to foresee possible challenges, to sense partners' and customers' needs, or to adjust quickly to unexpected situations and many others. The right conditions provided by the employers seem critical as well, as shown by the study [ASTOR, 2017]. Črešnar & Jevšenak [*Črešnar, Jevšenak,* 2019] argue that the Industry 4.0 business environment would be more open, understanding, collaborative, accepting, and generally more supportive. Much depends on the leadership and management culture, which should foster certain behaviors and attitudes. Unfortunately, such "nudging", guiding, or mentoring are often missing or not fully acknowledged by managers and CEOs. One can suggest that particularly millennials (and their values shaping subsequent attitudes and behavior) might be well prepared for it and also have an impact upon it, as they are in general more inclined toward values

Table 4. **Some Approaches to Defining the Skills Needed in the Age of Industry 4.0**

Concept	Contents
Generic skills [*Grzybowska, Łupicka*, 2017; *Kinkel et al.*, 2016]	• Creativity • Entrepreneurial thinking • Problem and conflict solving • Decision making • Analytical and research skills • Quick adaptation to unexpected situations • The need for courageous action • The ability to fail fast and rebound quickly • Joining forces with one's enemies according to the frenemy principle • Quick learning, unlearning, and relearning • The production of cross-over innovation
Engineer 4.0 [ASTOR, 2017]	• Strategic thinking • Interdisciplinary teamwork • Designing and developing algorithms intuitive for "ordinary people" • Coordinating human-machine cooperation • Close monitoring of and learning from competitors and peers • Analytical skills • Ambition and curiosity (self-motivation) • Striving and being motivated by self-development rather than financial benefits • Openness and activity • Openness to diversity, both in terms of contacts with people and tasks • Ability to communicate other very technical/detailed information with enthusiasm and optimism, which will prompt a positive response from listeners • Great attention to details • Striving for perfection • Ensuring the high quality of work and compliance with standards, rules, and procedures

Source: compiled by the author using the mentioned works.

connected to personal growth, emphasize openness to change, and understand the value of self-enhancement.

Clusters in the Context of Industry 4.0

There are various challenges and opportunities that arise for clusters due to Industry 4.0. At first glance, there is a contradiction rather than complementarity between two concepts (see Table 5). It may be argued that Industry 4.0 supports the idea that "distance does not matter" and that it suspends the importance of geographical co-location and spatial proximity. The features of internet communications might be perceived as defying the sticky, location-specific offer of clusters. Hence the main risk for clusters is to become an obsolete concept as Industry 4.0 facilitates distant collaboration and reduces the need for collocation or spatial proximity.

Yet, despite this inconsistency, clusters can contribute a great deal to the development of Industry 4.0. A previous study devoted explicitly to clusters' role in the fourth industrial revolution revealed different channels of influence [*Götz, Jankowska*, 2017]. The peculiarities of knowledge generation and dissemination critical for Industry 4.0 can be reconciled with the idiosyncratic features of innovation processes typical for clusters. The introduction of new business models triggered by the fourth industrial revolution such as the connected company with vanishing boundaries and the emergence of digital business ecosystems can be detected in mechanisms associated with clusters. Clusters seem to be well-positioned to act as a very promising policy tool organizing the implementation of the fourth industrial revolution and safeguarding the smooth digital transformation of businesses. Clusters can namely act as the laboratories for Industry 4.0 experiments, they provide a conducive environment for knowledge creation and dissemination, they serve as a policy tool for the implementation of advanced projects and are themselves the core of or nodes in the architecture of platforms or networks. The factor of spatial proximity also plays a crucial role. Not all ties with counterparts can be acted upon remotely. Cluster firms adopt the newest IT technologies with respect to the end-customers while they are reluctant to use remote channels for communication with subcontractors, suppliers, and other partners, which should be interpreted as a sign that they rely on flexible and trustworthy informal

Table 5. **Comparative Features of Clusters and Industry 4.0**

Dimensions	Cluster	Industry 4.0
Scope	Geographic, location-bound phenomenon	IT-facilitated and dispersed activities
Outcomes	Promote regional and local learning and production	Worldwide dispersion of activities and allows for connectivity of geographically scattered units
Drivers	Agglomeration and specialization	Urbanization and diversification

Source: compiled by the author.

communication that cannot be easily and efficiently virtualized in electronic form [*Belussi,* 2005].

Hence, it might be argued that cluster attributes are the right answer to Industry 4.0 challenges and that the properties of clusters are aligned with Industry 4.0 needs and well positioned to be the drivers for this movement. Nevertheless, those promoted by specific national strategies or appointed within dedicated programs might be particularly suitable.

Consider, for example, German clusters selected in the Leading-Edge Cluster Competition initiated by the Federal Ministry of Education and Research (BMBF)[5]. Selected cases can shed light on the various forms and roles clusters can play with respect to Industry 4.0.

ITS OWL cluster – Intelligent Technical Systems Ost-WestfalenLippe – in Paderborn represents such a flagship project in Industry 4.0. ITS OWL demonstrates how to harness clusters for digital business transformation. Being an alliance of more than 170 enterprises, universities, laboratories, and other partners, it is working on nearly 50 advanced projects.

CLIB2021 is a Düsseldorf-based cluster having a very diversified portfolio. This is an open innovation alliance active in biotechnology in which approximately 25% of members are international. It aims at networking stakeholders along and across value chains and in discovering new unexpected value chains in the field of bioeconomy. CLIB2021, while remaining open to external members, simultaneously integrates various sectors (chemical, food, cosmetics, pharmaceutics), works on competences from various areas (IP, access to markets, design etc.) and serves as a platform for joint projects. It further participates in H2020 funded initiatives, offers training opportunities, and establishes outposts in foreign markets.

Similarly, the cluster *Netzwerk Smart Production* from Manheim is meant chiefly as a tool for regional policy and technology development. Its members include such companies as Roche, SAP, ABB, and E&Y. The main task of cluster management is to contribute to the advancement of the digitalization of regional businesses, to facilitate networking among partners, and boost cooperation and export performance. Industry 4.0 is perceived as an instrument for making the region a "homeland of innovative pioneers".

On the other hand, the *Virtual Dimension Center (VDC)* in Fellbach is dedicated to advancing the development of technologies. It is a network for developing digital 3D models comprising of some 100 members dealing with Industry 4.0 processes such as simulation, visualization, product lifecycle management (PLM), computer aided engineering (CAE), and virtual reality (VR) along the entire virtual engineering value chain. VDC management provides opportunities for seminars and workshops, conducts match-making events, helps companies access relevant information and proper marketing, enables technology transfer, and assists in funding management.

All of these cases demonstrate that there is no standard unified model of an "Industry 4.0 cluster". It is still too early to find any clear evidence of the success of such initiatives, nevertheless, they all help raise awareness and indisputably facilitate the wider reach of Industry 4.0 among SMEs and their employees.

The managers of cluster organizations should play a special role in this respect. In particular, as the case of ITS OWL shows, they need to work not only on ensuring the right accumulation of knowledge and innovation or facilitate the generation of know-how but must also safeguard the transfer of technology and guarantee the right access for all its members. This can materialize by organizing different events, demonstration centers, training and testing, or pilot project presentations. Cluster managers need to prevent possible cluster lock-in due to overspecialization and a lack of diversity. They should provide the necessary openness and inflow of fresh ideas, which are so critical in the rapidly changing business environment of the digital era. They may develop brand and cluster identity as necessary elements for cluster visibility.

The role of universities and other educational bodies also cannot be underestimated [Lis 2018]. Besides achieving academic excellence, they need to closely cooperate with local business and industry to make sure that the curricula and provided courses are aligned with cluster members' expectations, in particular, it is necessary that they address the needs of the local labor market. Specifically, the emerging trend of entrepreneurial universities deserves attention [*Audretsch,* 2014]. The role they played in the local context can vary but it usually draws on establishing incubators and technology transfer centers or intellectual property spin offs [*Pugh et al.,* 2018]. Besides generating and transferring knowledge, many of these universities are supposed to actively engage in the region by fostering entrepreneurship and entrepreneurial attitudes which can contribute to regional development [*Audretsch, Keilbach,* 2008; *Audretsch,* 2014]. All these activities are aimed at enhancing innovativeness and creativity which should translate into the improved efficiency and competitiveness of local entities. Such a role is of even more relevance in the rapidly changing and data-driven analytical age, when close collaboration among academia and industry or business seems to be a condition *sine qua non* for a smooth transformation of business and society. Obviously, much would depend upon the character of the local innovation sys-

[5] In total there were 15 winners of the Leading-Edge Cluster Competition. For a detailed description see: http://www.clusterplattform.de/CLUSTER/Navigation/EN/Home/home.html.

tem, whether based on DUI principle – "learning-by-doing, by-using, and by-interacting" or STI – science and technology-based innovation [*Jensen et al.,* 2007]. The DUI system is associated with synthetic knowledge bases (i.e. recombination of different knowledge with a practical, engineering-based purpose) and innovation mostly generated by the capacity to interact with suppliers, customers, and competitors [*Fitjar, Rodriguez-Pose,* 2013]. The STI system builds upon high R&D expenditures, investments in highly skilled scientific human resources and advanced technologies and infrastructure, supports interactions with research centers and universities, and as a result, generates mainly analytical knowledge (i.e. scientific principles, discoveries, and formulas).

There is a growing body of literature on the positive externalities of universities in terms of shaping new venture creation [*Audretsch et al.,* 2016]. They might design and develop more vocationally oriented training programs and provide it as part of a lifelong learning initiative. Hence, they would enable the already educated employees of cluster firms to retrain and requalify in order to gain new skills and competences. In Poland for instance, the idea of incubators of Industry 4.0 Leaders" has been developed[6]. Affiliated with Polish technical universities, these incubators aim to promote Industry 4.0 among Polish businesses and industries and to facilitate the uptake of Industry 4.0 mainly among SMEs. The leaders of the technological and digital transformation are trained there in order to act later as multipliers and train the next generation of leaders. Besides providing dedicated module courses, they disseminate information, conduct visits to selected best-practice firms, offer seminars and workshops, ensure access to demonstration models, competence centers and living labs for SMEs, provide consultation services and training as well as assist firms during the implementation phase. It is now worth mentioning the HCAT+ from the Hamburg Aviation Cluster[7]. The Hamburg Centre for Aviation Training works on safeguarding a highly qualified workforce and human capital for the aerospace industry in the region. It sees itself as a coordinator and moderator in terms of training and qualifying personnel. By conducting projects of common interests, it aims to buttress the capabilities especially of SMEs in terms of sustainable human resource development. One of the projects, DigitnetAir, brings together SMEs (responsible for developing new concepts in terms of future Industry 4.0 work), education (schools and universities responsible for developing future oriented and demand driven modules for teaching new skills and competences), and technology (labs and universities in charge of developing and testing new solutions in Industry 4.0 sectors as well as demonstrations and prototypes). DigitnetAir is a unique alliance that aims at countering the negative consequences of qualified labor skill shortages but also at adjusting the teaching and training systems to modern challenges induced by the fourth industrial revolution. It embodies the forward-looking aspects of nurturing the relevant skills by anticipating future trends and predicting local labor market needs in a timely manner.

Conclusions

Industry 4.0, though it is still used in different contexts and lacks an explicit definition, will certainly revolutionize the global economy [*Brettel et al.,* 2014]. This paper outlines the interdependencies between crucial categories such as: clusters, Industry 4.0, GVCs, networks, and skills. Industry 4.0 transforms global value chains into adaptive networks of interrelated entities. In order for companies to be able to adapt to these processes, their employees need to be equipped with a new set of critical skills. Clusters seem well positioned to foster such an adaptation. Some features of modern production systems and digital transformation embody many of the properties of clusters. The briefly reviewed cases of German Industry 4.0 clusters show how digital production can be arranged via networking within GVCs. These cases confirm our suggestion that in order to be the drivers for Industry 4.0, clusters should stimulate firm's agility which, besides being shaped by the cluster's coopetitive ecosystem, obviously derives from the appropriate competences and skills of its employees.

Companies acting globally and undergoing digital transformation benefit from participation in clusters. The cluster environment fosters agility that allows a company to embed into new value chains and integrated networks.

As our analysis showed, clusters have the potential to ensure a smooth digital business transformation and foster innovation at the local level. They form a "culture of cooperation", contributing to increasing the flexibility of companies by developing such qualities as adaptability, responsiveness, and a combination of responsive strategic and operational management.

Our study aims to expand the knowledge base for the development of regional development programs that take into account the specifics of the target territories and create favorable conditions for networking. This paper, however, does suffer from certain limitations. Using an essay format, it has a more speculative character, though, at current stage of our understanding it may be seen as setting the stage and is an invitation for further research and discussion. The article

[6] http://przemysl40.polsl.pl

[7] https://www.hcatplus.de

does not exhaust all other likely interdependencies between these two concepts [*Götz, Jankowska,* 2017] nor does it finish the discussion on clusters' role in modern global production chains [*De Marchi et al.,* 2018]. The current literature mainly focuses on technical views on digitalization. New alternative channels of "clusters-Industry 4.0" should be identified and discussed. For instance, the role of the reduction of uncertainty, the importance of clusters as ecosystem for SMEs might deserve scholarly attention. Finally, the idea that clusters would simply result from an Industry-4.0-triggered transformation as assumed by Myrdal cumulative causation [*Myrdal,* 1953; *Smit et al.,* 2016] should be explored.

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The Risks of Digitalization and the Adaptation of Regional Labor Markets in Russia

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Abstract

The implementation of new automation technologies together with the development of artificial intelligence can free up a significant amount of labor. This sharply increases the risks of digital transformation. At the same time, certain regions and cities differ greatly in their ability to adapt to future changes. In this article, we seek to determine the capabilities of Russian regions to reduce risks and adapt to digital transformation. The literature stipulates that there are several factors able to reduce these risks. First of all, they are associated with retraining, ICT and STEAM-technologies' development, the promotion of economic activities that are less subject to automation. As a result of econometric calculations, we identified several factors that contribute to the new industries' development (in our case, ICT development), and, accordingly, increase regional adaptivity. These factors include diversification, the concentration of human capital, favorable entrepreneurship conditions, the creative potential of residents, and the development of ICT infrastructure. We identified several regions with high social risks and low adaptivity, which are mainly the poorly developed regions of southern Russia, where entrepreneurial risks are high, STEAM specialists are not trained, shadow economy is large. This work contributes policy tools for adaptation to digital transformation.

Keywords: digital economy; robots; STEAM; automation risks; technological exclusion; nescience economy; human capital; entrepreneurship; ICT

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With the development of new technologies, many routine operations, primarily simple manual work, gradually become automated [*Brynjolfsson, McAfee,* 2014]. At the same time artificial intelligence (AI) systems are beginning to threaten medium-skilled professional jobs such as drivers, sales assistants, and technologists. The main risk associated with accelerated digital transformation and the automation of production is that people will find it difficult to adapt to the changed situation in time. Although until recently the development of digital technologies in Russia was slower than in the world's leading countries [OECD, 2017; *Abdrakhmanova et al.,* 2018], even with the relatively smooth transition to automation and no large-scale "technological" unemployment (which can be achieved at the cost of major monetary injections)[1], it will still be necessary to adapt to the digital economy. This implies that people will have to learn new approaches to doing business, running their households, using public services, and so on. Meanwhile, Russian regions are quite diverse in terms of both their digitalization potential and their ability to adapt to changing conditions [*Zemtsov,* 2017, 2018].

In recent years, the number of able-bodied Russian population has been steadily declining, so the retirement age was raised to accomplish economic and social objectives. In the foreseeable future, this trend is likely to transform the labor market. The development of a digital economy may provide an answer to the declining workforce problem and serve as an additional economic growth factor; however, at the same time it might lead to significantly decreased employment, and increased unemployment among less skilled workers. For example, in the US, the use of industrial robots resulted in considerably reduced employment and wages [*Acemoglu, Restrepo,* 2017]. The use of digital technologies is a strategic development goal in Russia for the period until 2024.[2] The implementation of national projects to promote the digital economy and labor productivity can lead to the liquidation of a large number of jobs, about 12.5 million [CMASF, 2018]. These risks affect workers employed in primary industries and manufacturing, where the shares of manual work and routine operations are higher [*Berger, Frey,* 2017].

This paper considers Russian regions' potential to adapt to the digital economy and analyzes conditions for new job creation in the information and communication technology (ICT) sector. Regions more vulnerable to the above risks are identified. The data and the methods used to identify factors affecting ICT development are described. Regional adaptation prospects are discussed, taking into account the identified factors and a typology of regions is suggested. Recommendations on reducing digitalization-related risks are provided.

Literature Review

Smart technologies are rapidly penetrating practically all key sectors including municipal services, transport, retail, education, and medicine. [*Brynjolfsson, McAfee,* 2014; *Schwab,* 2017]. By changing the established economic structure, disruptive innovations create conditions for the "disappearance" of certain industries that employ a large number of workers, mostly poorly skilled ones. However, given the current rate of S&T development, it cannot be ruled out that in the near future automation will also affect more highly skilled labor. This implies a totally different scale of changes in the social sphere and economy.

The prospects for the robotization of various jobs are being actively explored in all countries. Experts at the University of Oxford suggested a methodology for identifying more vulnerable industries, taking into account the use of social and creative intelligence as well as specific aspects of perception [*Frey, Osborne,* 2017]. Having applied this methodology to the Russian context [*Zemtsov,* 2017], it was concluded that 26.5% of jobs were highly likely to be automated. Occupations employing the largest numbers of people in Russia are particularly susceptible to these threats, such as sales assistants, drivers, security guards, and movers (in total about 28 million) [*Zemtsov,* 2018]. The methodology suggested by McKinsey [*Manyika et al.,* 2017] allows one to analyze the aggregated industries, identifying routine work operations in each of them. This makes it possible to estimate the automation potential for any economy based on the assumption that standard functions will be proliferating at the same rate in different countries. If new technologies are introduced simultaneously, at least half of able-bodied Russians (about 40 million people) can potentially be ousted by robots [*Zemtsov*, 2018]. However, the fact that such processes take time allows a country to prepare for them in advance.

Our study shows that less developed regions turn out to be more vulnerable. These include the Republics of Ingushetia, Chechnya, Dagestan, Karachai-Cherkessia, Kabardino-Balkaria, and Tyva. Their economies have high shares of "automatable" industries (retail, agriculture, and transport), and largely remain in the "shadow economy".

Automation will also affect the raw material producing regions such as the Nenets, Yamal-Nenets, and

[1] The experience of the city of Tolyatti in the Samara Region, where 70,000 Avtovaz workers were laid off due to automation, shows that federal policy can be quite inefficient. Government support was mainly provided to pay one-off redundancy compensation, grant subsidies to start one's own businesses, put in place infrastructure for small technology companies (in particular engineering firms), but it did not solve the problems faced by the majority of the residents. So there are grounds to fear that when the rate of automation increases, the government will not be able to provide adequate adaptation tools in many cities and regions.

[2] The RF Presidential Decree No. 204 "On national goals and strategic development objectives for the Russian Federation for the period until 2024" of 7 May, 2018. Access mode: http://www.kremlin.ru/events/president/news/57425, last accessed on 15.04.2019.

Khanty-Mansi Autonomous Districts where mining technologies dominate production, along with oil and gas transportation. This trend will also affect developed regions with high shares of manufacturing in their economies, which already use automation technologies, in particular the regions of Leningrad, Chelyabinsk, Rostov, Sverdlovsk, and the Republic of Bashkortostan.

Compared with developed countries, the penetration of advanced technologies is currently happening in Russia at a slower rate. This is due to low population density, uneven distribution of economic activities, low income, insufficient availability of technologies, and weak links between the territories. The government policy to limit labor market freedom plays a particularly important role. In effect a ban on laying off large numbers of workers from major core enterprises is in place. However, the need to make the economy more competitive will eventually prevail over the social risks. When this happens the rate of digitalization would sharply increase, while opportunities for the people and the economy to adapt would shrink [*Zemtsov, Baburin*, 2014]. Increasingly more workers will have to find new occupations, master new technologies, and acquire new skills. There is a danger that the application of digital technologies will outpace retraining and new job creation. People who have lost their jobs and were unable to adapt to the new situation may create an "ignorance-based economy" [*Zemtsov,* 2018]. We use this term to describe an economic segment where people are engaged in "second-rate" activities such as the natural economy or shadow sector, with no advanced technologies and no need for continuous training. Technological exclusion[3] from the modern economy may lead to sharply increased pressure on regional and municipal budgets, since it will require active social support. In more recent studies [*Arntz et al.,* 2017] attempts were made to integrate workers' ability to retrain into the model, along with other mechanisms for adapting the labor market to changing conditions. Under this approach, the estimates of potential technological exclusion only marginally exceed the current unemployment level. Still, with a high rate of digitalization, the latter figure may double. Companies' innovative activity and retraining efforts usually have a positive effect on employment. Entrepreneurship and creative intelligence provide opportunities to deal with the labor market crisis [*Sorgner,* 2017]. Creating a new business as a way of self-realization contributes to new job creation.

Other mechanisms for adapting to robotization imply active training in STEAM disciplines: science, technology, engineering, arts, and mathematics. These are the spheres of activities were robots cannot yet replace humans [*LaGrandeur, Hughes,* 2017; *Zemtsov,* 2018].

Retraining may smooth over the social risks of digital transformation, so the latter are likely to be much lower in the regions with a high level of education [*Chang, Huynh,* 2016], where workers are better able to acquire new knowledge, master new technologies, and participate in continuous learning. To support conclusions by a number of international studies, [*Zemtsov,* 2018] demonstrates that in Russia, the social risks associated with automation are lower in technologically developed regions with a high share of urban residents, entrepreneurs, and workers with higher education.

New industries, activity areas, and professions are constantly emerging in the present-day context [*Berger, Frey,* 2016]. The ICT sector is the most rapidly growing industry with new jobs being created on a massive scale which are less susceptible to automation.

According to certain estimates, about twice as many jobs will be created by 2030 than cut due to digitalization [WEF, 2018]. Unfortunately, these processes will not be aligned territorially. Robotization is likely to affect developing countries first, with a high share of mining industries, such as Indonesia, Vietnam, India, and China. On the other hand, favorable conditions for new job creation in the ICT sector have largely emerged in developed nations such as the US, Japan, the UK, and Germany. This mismatch is also in place in Russia: the risks are highest in regions where manufacturing, agriculture, and mining have significant shares in the economy, while advanced high-tech companies are mainly being created in major urban agglomerations where the service sector dominates [*Zemtsov,* 2018].

The share of routine operations is diminishing, while that of creative work is growing [*Autor et al.,* 2003]. The share of workers with "universal" skills such as programming, new technology development, and creative thinking on the US labor market is on the rise [*Michaels et al.,* 2013]. If in the 1970s the correlation between the number of new jobs and the share of workers with universal competences was low, in recent years it has been growing [*Berger, Frey,* 2016]. Computers are increasingly used to deal with work-related tasks, which have become more complex. In Russia these processes are happening at a slower rate [*Gimpelson, Kapeliushnikov,* 2015; *Zemtsov,* 2018] due to the low competitiveness of most companies, working for which does not require the serious upgrading of skills. Obsolete production facilities with the wide application of manual and routine work do not have demand for new competences.

Digital transformation and the emergence of new industries largely depend on the quality of information and communication infrastructure. Russia has a high level of digital inequality between regions and locations. Closer to large urban agglomerations the situation is better, but in many Far Eastern, Arctic, and

[3] Similar processes were observed in Russia at the time when computers started to proliferate: numerous members of older population groups in effect were excluded from modern economic activities. However, in the course of the natural alternation of generations, social risks were avoided. However, the rate of digitalization can be much higher, while changes are much more radical.

North Caucasus towns people still do not have broadband internet access. These disproportions have been smoothed over by wide mobile coverage[4]. Regions with developed ICT infrastructure tend to have larger ICT markets, offer better opportunities for online trade and other businesses, and for training (offline and online alike) [World Bank, 2016]. They have built a solid foundation for the growth of advanced sectors of the economy such as additive technologies, virtual reality, and telemedicine. Creating conditions for new activity types, primarily in the ICT sector, will help economies to better adapt to digitalization.

Thor Berger and Carl Frey identified factors contributing to changes in the sectoral structure of the US cities' economies, based on the sectors included in the new edition of the national job classification (mainly related to the ICT sphere) [*Berger, Frey,* 2016, 2017]. Diverse economic activities in megacities, the rate of ICT application, and the colossal flow of students and newly trained professionals turn out to be the key drivers of new job creation in cities. Let us take a closer look at each of these factors.

Diverse economic activities are a leading economic development factor [*Jacobs,* 1969]. A city offers opportunities to apply a wide range of competences and skills. This leads to the emergence of new, more advanced industries that can grow due to a large market.

Cities with a *high share of ICT professionals* among university graduates were able to create new jobs in new industries much more rapidly than others, primarily in the ICT sector [*Lin,* 2011; *Beaudry et al.,* 2010]. A *large supply of well-trained students* provides a basis for the emergence of prospective industries, because many young professionals subsequently become new technology developers and establish their own companies. Regions that train just a few dozen ICT professionals a year are unlikely to achieve breakthrough solutions or encourage the creation of rapidly growing start-ups.

In areas where routine activities dominate, digitalization leads to reduced employment, while in regions that already have a high share of creative workers, new industries tend to emerge [*Moretti,* 2012; *Autor, Dorn,* 2013]. Specializing in specific production activities may result in a lock-in, when the whole community, universities, and companies are focused on promoting the development of a single industry [*Martin,* 2010]. Therefore the predominance of manufacturing may negatively affect the emergence and growth of new industries [*Berger, Frey,* 2016].

In the US, employment in high-tech industries is linked to the increased concentration of highly educated people [*Beaudry et al.,* 2010; *Chen,* 2012], while in China it largely depends on better standards of living [*Chen,* 2012].

Thus it is important not just to retain, but also attract highly skilled workers to promote the development of new industries. Various studies confirm that human capital properties in the region may accumulate with time, which means this factor deserves particular attention when regional policies are implemented.

Another important driver affecting the emergence and growth of new sectors of the economy is R&D potential, which can be measured by the number of R&D personnel, amount of relevant expenditures, or number of patents [*Zemtsov et al.,* 2016; *Berger, Frey,* 2017]. The more knowledge and skills are accumulated in a regional community, the higher is the potential for technological progress, and the emergence of new activity areas. In the early stages, the application of new information technologies in Russia was largely determined by the availability of R&D centers, whose highly skilled personnel needed computers to process large volumes of data. A strong correlation was established between the number of regional R&D personnel in 1991 and the level of ICT in 2011 [*Ivanov,* 2016]. Employment in the US high-tech sector [*Li,* 2000] is also affected by the concentration of R&D institutes and students.

The following **hypotheses** are put forward on the basis of the literature review:

Hypothesis 1: Large cities with diverse economic activities and major markets have greater potential for the development of a new economy.

Hypothesis 2: The growth of prospective industries requires a high concentration of human capital: the higher the education level, the more opportunities are available for training, mastering new technologies and new activity types.

Hypothesis 3: Information and communication infrastructure is particularly important for the "young" sectors.

Hypothesis 4: High entrepreneurial activity and optimal conditions for doing business (establishing and running start-ups) create a firm foundation for the emergence of new industries.

Hypothesis 5: High levels of innovative activity in the region (as an indicator of the residents' accumulated innovative and creative potential) promotes the growth of emerging sectors.

Hypothesis 6: Employment in the information technology industry tends to be lower in regions where manual and routine work dominate (such as agriculture and manufacturing).

Data and Methodology

Reducing the risks and increasing regions' potential to adapt to digital transformation would require creating conditions for the development of new industries,

[4] For this reason, in the North, for example, the number of active SIM cards per person is much higher than in Central Russia: mobile communications are used not just for making calls but also for accessing the internet.

primarily in the IT sector. Therefore we have used the share of workers employed in the information sector[5] in the total workforce[6] as the dependent variable. In other words, we measured the role of information technology and thus indirectly the level of digital economy development in Russian regions. According to 2017 data, the share of IT personnel in the total Russian workforce amounted to just 1.06% and in the high-tech sector about 3.1% [*Zemtsov et al.,* 2019]. In absolute terms, there are about 472,000 IT professionals out of 44.3 million workers. In a number of regions, their share remained persistently low throughout the period under consideration (2010-2017) (Figure 1), including the Kursk and Leningrad Regions, the Republics of Adygei, Dagestan, Kabardino-Balkaria, Karachai-Cherkessia, Chechnya, and the Chukotka Autonomous District (just 58 IT professionals). In 2017, capital urban agglomerations were far ahead of other areas: Moscow had 3.3% (about 160,000 IT workers), and St. Petersburg 3.4% (approximately 50,000); combined, they account for 44.5% of all IT personnel in the country. The regional averages were also higher in other major Russian urban agglomerations such as the Novosibirsk (1.6%), Yaroslavl, Tomsk, Ryazan, Samara, and Nizhniy Novgorod Regions, and the Republic of Tatarstan. Taken together, these regions employ 63,000 IT professionals (or about 13.3% of their total number).

In most leading regions the share of IT workers grew between 2010-2016. However, over the latest year the number of such professionals decreased in the Nizhniy Novgorod and Samara Regions, and in Tatarstan. This might be evidence of negative trends in these regions' economies but it may also be explained by the changes in the main Russian Classification of Economic Activities (OKVED).

In line with the suggested hypotheses, we propose the following empirical model to explain the factors affecting the development of the IT industry:

$$lnIT_{i,t} = alnDiversity + \beta lnHumanCapital_{i,t} + \gamma lnICTinf_{i,t} + \\ + \delta lnEntrepreneurship_{i,t} + \epsilon lnInnov_{i,t} + \\ + \theta lnEconomicSpecialization_{i,t} + \varepsilon_{i,t}$$

where:

IT is the share of IT workers in the total regional workforce, %

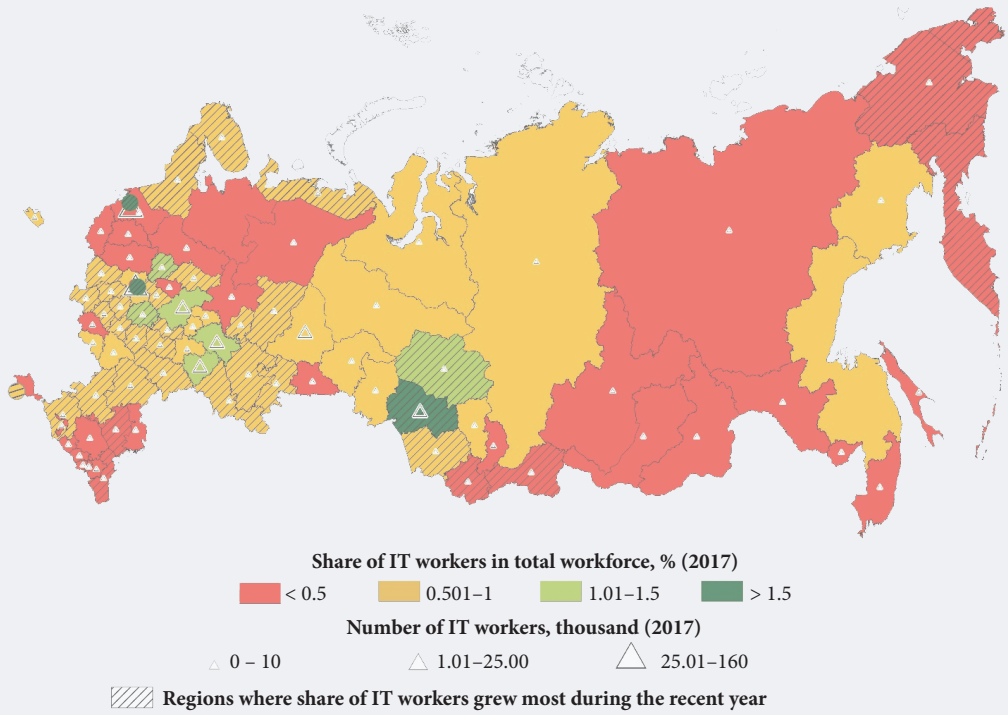
i is the Russian region;

t is the year;

Diversity are variables measuring the diversity of economic activities and agglomeration effects [*Jacobs*, 1969];

HumanCapital are variables measuring the concentration of human capital in the region, and residents' education level;

Figure 1. **Development Level of the IT Sector in Russian Regions (2017)**



Source: composed by the authors based on Rosstat data.

[5] Activity types: the development of hardware and software, relevant consulting, and other related services; IT-related activities.

[6] Total number of workers on the payroll of all organizations. Access mode: https://www.fedstat.ru/indicator/43007, last accessed on 12.01.2019.

Table 1. **Variables Applied in the Model**

Variable	Designation	Indicator	Expected effect	Source
Diversity	ln_city	Number of regional capital residents, people	+	Rosstat
Human capital	ln_high_ed	Share of workers with higher education, %	+	Rosstat
	ln_high_urb_ed	Share of employed urban residents with higher education in the previous year, %	+	[*Zemtsov et al.*, 2016]
	ln_stud(t-10)	Share of students in the population 10 years ago, %*	+	Rosstat
ICT infrastructure	ln_int	Share of people (households) with internet access, %	+	Rosstat
	ln_int2	Share of organizations with internet access speed of at least 2 Mbit/s in total number of organizations (%, annual value)	+	Rosstat, [*Zemtsov et al.*, 2019]
Conditions for the development of entrepreneurship	ln_firm	Ratio of the number of small enterprises to workforce, *units per 10,000 people*	+	[*Barinova et al.*, 2018]
Innovation potential	ln_patent	Ratio of the number of potentially commercialized patents to the number of employed urban residents with higher education, *units per 10,000 people.*	+	[*Zemtsov et al.*, 2016]
Specific features of economic structure	ln_budg_emp	Share of workers employed by companies with public participation in total workforce, %	-	Rosstat, authors' calculations
	ln_manuf	Share of workers employed in agriculture and manufacturing, %	-	Rosstat, authors' calculations

* Number of students indicated with a 10-year temporal lag, since we assume students do not increase the region's human capital straight away.

Source: compiled by the authors.

ICT_inf are variables measuring the development level of ICT infrastructure in the region and the availability of internet access;

Entrepreneurship are variables describing the conditions for business development and the density of entrepreneurial activity;

Innov are variables measuring innovative potential, accumulated scientific knowledge, and researchers' creative potential;

EcononomicSpecialization are control variables describing specific features of regional economic structures: the share of sectors where routine and manual work is common, i.e., those where opportunities for applying IT remain low. Shares of workers employed in agriculture and manufacturing and in the public sector were used for this purpose. The latter indicator describes the level of regional development, since in a number of Russian regions the public sector remains the only source of jobs.

Due to changes in the OKVED, the time series was limited to 2010 and 2016. Data for 2017 is not fully compatible with the statistics for the preceding years. All figures were taken from official Rosstat sources, unless indicated otherwise.

Table 1 presents the main factors and the indicators used to measure them. To test multicollinearity, Table 2 presents pair correlation coefficients for the variables. All indicators were logarithmized.

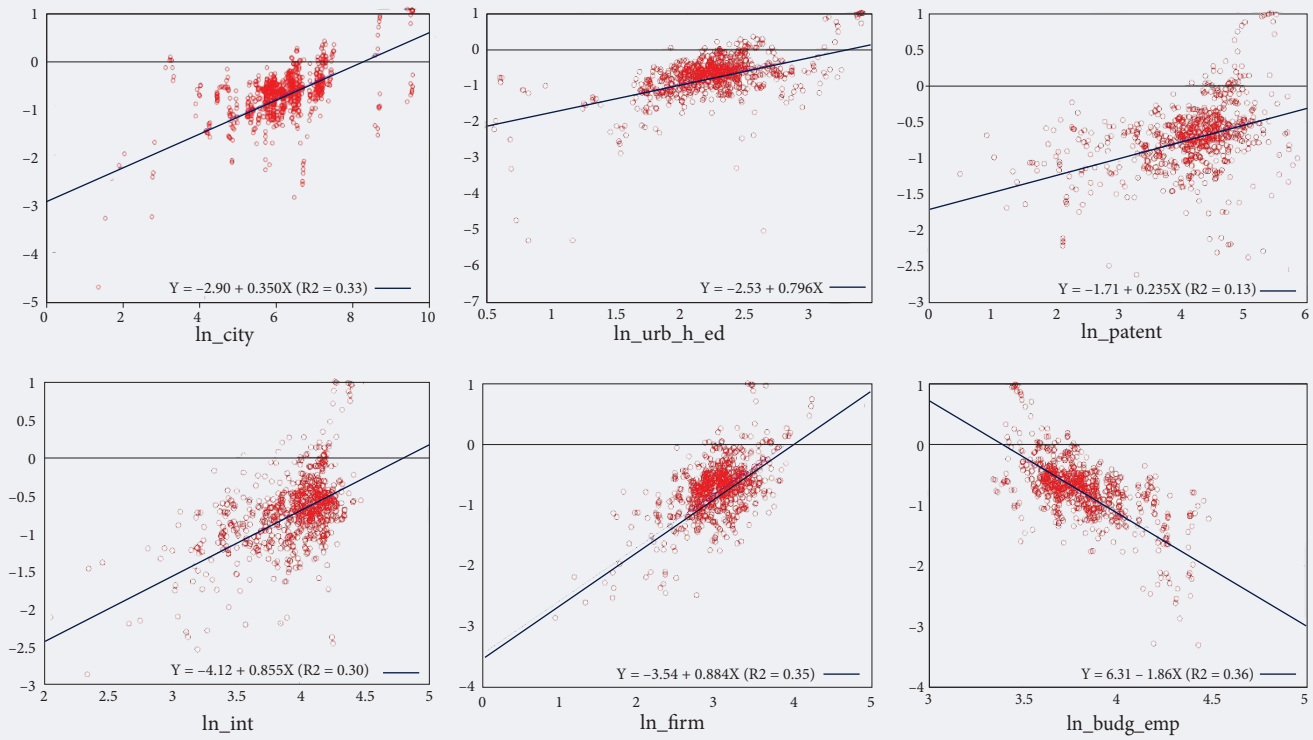
Figure 2 presents scatter plots to help better understand the directions and types of correlation between the dependent variables and the main factors.

A fixed effects model was applied to estimate multivariate regression coefficients as the most appropriate for a regional study. The set of identified factors is sufficient to describe the characteristics of regions that were more successful in creating new sectors of the economy. However, it is not enough to understand the relationship between the existing risks and the Russian regions' potential. Therefore additional research was conducted.

At the *first stage*, to obtain a better understanding, the number and share of graduates specializing in STEAM professions[7] was estimated (Figure 3), which affects the possible future number of non-routine jobs. In total, about 332,000 such professionals were trained in Russia or less than 20% of the total number of graduates. Education systems in innovative regions such as the Tomsk, Samara, Voronezh Regions, the cities of Sevastopol and St. Petersburg, and the Republics of Mari El and Tatarstan turned out to be most STEAM-oriented ones (more than 25% of all graduates specialized in STEAM disciplines in these regions).

[7] Data to calculate the admission and graduation of students specializing in STEAM disciplines was collected from reports published by the Russian Ministry of Education and Science based on federal statistical observation forms VPO-1 and SPO. The STEM Degree List approved by the US Department of Homeland Security in 2010 was used as a foundation. The current list (>400 training areas) is available on ICE.gov. The CIP codes (Classification of Instructional Programs) were converted into profession codes in line with the Russian Ministry of Education and Science's order No. 1061 of 12.09.2013. The following knowledge areas were taken into account: mathematics and engineering sciences, engineering, technology, arts, and culture. Researchers who have successfully defended their dissertations in all scientific domains (PhD and Doctor of Science) were added to the number of graduates.

Figure 2. **Scatter Plots between Independent and Dependent Variables**



Source: composed by the authors.

The 19 regions that train more than 5,000 professionals a year (Figure 3) account for about 63% of the total number of graduates. Mostly it is the largest urban agglomerations in the country.

At the *second* stage, the automation-related risks the regions faced were compared with their adaptation potential. As such, the measurements used for this purpose were only loosely related to future technology unemployment problems [*Zemtsov,* 2018]. They only allow one to assess the threats: the higher the share of the population whose jobs can potentially be automated, the higher the risk of technological exclusion. However, if at the same time factors affecting conditions for the emergence of new industries are poorly developed in a region, it creates an additional risk of an "ignorance-based economy" emerging, along with "old industry" and "old service" areas with a high level of shadow employment and unemployment, low income, and other social issues.

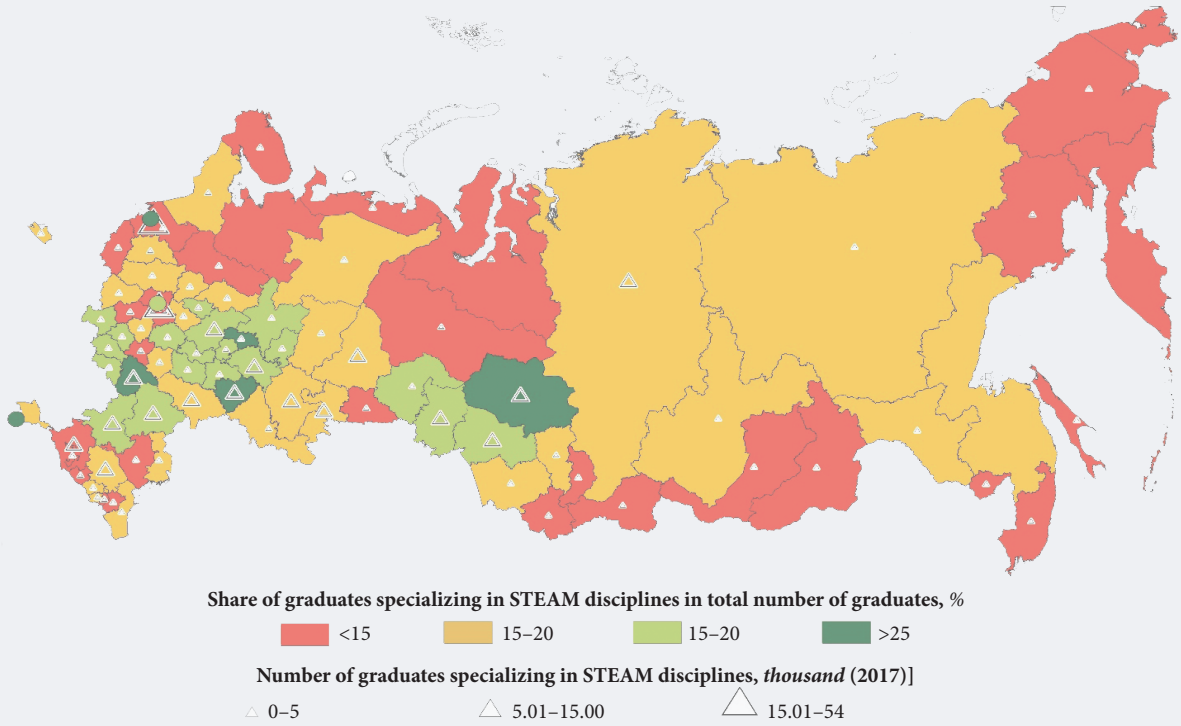
In Figure 4, the *X* axis represents automation-related risks (the share of regions' residents whose jobs may be cut in the total workforce, as a percentage) (see [*Zemtsov,* 2018] for more). The *Y* axes shows regions' potential to adapt. It was measured as the ratio of the number of IT workers (Figure 1) and graduates specializing in STEAM disciplines (Figure 3) to the

Table 2. **Cross-Correlation Matrix**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
[1] ln_IT	1	0.55	0.22	0.58	0.48	0.66	0.51	0.36	0.65	–0.62	0.26
[2] ln_city		1	0.2	0.38	0.35	0.36	0.31	0.61	0.38	–0.52	0.23
[3] ln_high_ed			1	0.49	0.49	0.19	0.32	0.01	0.21	–0.11	–0.28
[4] ln_urb_h_ed				1	0.4	0.55	0.35	0.08	0.58	–0.59	0.2
[5] ln_stud(t-10)					1	0.4	0.49	0.37	0.44	–0.19	–0.08
[6] ln_int						1	0.65	0.12	0.53	–0.48	0.21
[7] ln_int2							1	0.21	0.41	–0.45	0.15
[8] ln_patent								1	0.22	–0.34	0.3
[9] ln_firm									1	–0.57	0.23
[10] ln_budg_emp										1	–0.65
[11] ln_manuf											1

Source: composed by the authors.

Figure 3. **Number of Graduates Specializing in STEAM Disciplines in Russian Regions (2017)**



Source: composed by the authors.

number of able-bodied residents whose jobs face the risk of automation[8] [*Zemtsov,* 2018]. In other words, we assessed the balance between the existing risks and the IT sector's and educational system's potential to train STEAM professionals. The higher this indicator value is, the better the overall conditions for adaptation, since a strong IT sector is already in place and the educational system is training STEAM professionals. For example, in Moscow and St. Petersburg this ratio is close to 100% (Figure 4). Accordingly, at the last stage the resulting ratio was used to develop a typology of regions, identify problem territories, and prepare recommendations.

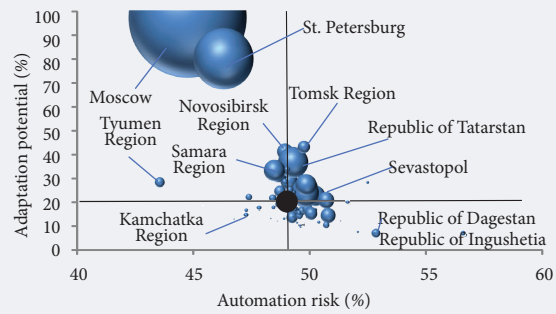
Results

Our calculations (Table 3) did not refute any of the suggested hypotheses. Generally, the important roles of the factors affecting the emergence of new industries (in our case information technology), and people's ability to adapt to automation described in the literature was confirmed. The high diversity of jobs and large labor markets in major cities determine self-realization opportunities for creative professionals and promote the emergence of new industries. Accordingly, in regions where the number of capital city residents was 1% larger, the share of workers employed in the IT sector was 0.85–0.9% higher.

In regions with a high concentration of human capital (a large number of employed urban residents with higher education) the IT sector develops at a higher rate.

The number of students also turned out to be a significant variable in a number of models, which suggests the need to accumulate human capital. The thesis that developed ICT infrastructure is a basic factor affecting the development of information technologies at the regional level was also confirmed.

Figure 4. **Distribution of Regions by Robotization Risks, and their Adaptation Potential**



Note: The dot size reflects the number of graduates specializing in STEAM disciplines.

Source: composed by the authors.

[8] The estimated number for 2015 [*Zemtsov*, 2018] is divided by 15, since we assume the most favorable scenario in the field of employment, when automation takes place at a steady rate over the next 15 years.

Table 3. **Assessment of Regional Factors Affecting the Emergence of New Industries**

Variable type and codes		1	3	4	5	6	7
Constant		-10.6 (1.17)***	-1.01 (1.99)	0.34 (1.93)	-3.15 (193)	-6.84 (0.75)***	-4.4 (1.84)**
Diversity	ln_city	1.25 (0.06)***	1.13 (0.04)***	1.12 (0.05)***	0.95 (0.05)***	0.98 (0.04)***	0.85 (0.06)***
Human capital	ln_high_ed	0.54 (0.3)*			0.4 (0.18)**		0.34 (0.16)**
	ln_high_urb_ed		0.35 (0.18)**	0.41 (0.21)**			
	Stud(t-10)	0.38 (0.12)***	0.17 (0.09)*	0.17 (0.1)*		0.17 (0.08)**	
ICT infrastructure	ln_internet					0.35 (0.04)***	0.28 (0.06)***
	ln_int2				0.14 (0.04)***		
Conditions for development of entrepreneurship	ln_firm				0.17 (0.05)***		0.18 (0.06)***
Specific features of economic structure	Ln_budg_emp		-1.91 (0.45)***	-1.84 (0.45)***	-1.15 (0.4)***		-1.18 (0.4)***
	ln_manuf		-0.76 (0.29)***	-0.72 (0.3)**	-0.47 (0.24)**	-0.47 (0.24)**	
Innovative potential	ln_patent			0.04 (0.02)**	0.04 (0.02)**		0.04 (0.02)**
LSDV R2		0.89	0.904	0.901	0.909	0.911	0.912
Within R2		0.457	0.522	0.520	0.557	0.559	0.574
Schwarz criterion		327.2	266.9	232.5	199.4	215.3	170.8

Note: a fixed effects model was applied. The number of observations was 561. Growth was measured for 83 regions in 2010-2016. Robust standard errors are indicated in the brackets. The share of ICT workers in the total workforce (%) was used as the dependent variable (%). All variables were logarithmized.

Legend:

ln_city — size of regional capital city's population (*people*)
ln_high_ed — share of workers with higher education (%)
ln_high_urb_ed — share of employed urban residents with higher education in the previous year (%)
Stud(t-10) — share of students in population 10 years ago (%)
ln_internet — share of individuals (households) with internet access (%)
ln_int2 — share of organizations with internet access speed of at least 2 Mbit/s in total number of organizations (%, annual values)
ln_firm — ratio of number of small enterprises to number of workforce (*units per 10,000 people*)
Ln_budg_emp — share of workers employed in public sector (organizations funded by the state budget and state-owned companies) (%)
ln_manuf — share of workers employed in agriculture and manufacturing (%)
ln_patent — ratio of the number of potentially commercialized patents to the number of employed urban residents with higher education, (*units per 10,000 people*)

Source: composed by the authors.

Another significant indicator is patenting activity, which reflects innovative potential, the new technology development rate, and accumulated knowledge base. High innovative activity implies broad opportunities for converting ideas into technologies and thus for the emergence of new industries.

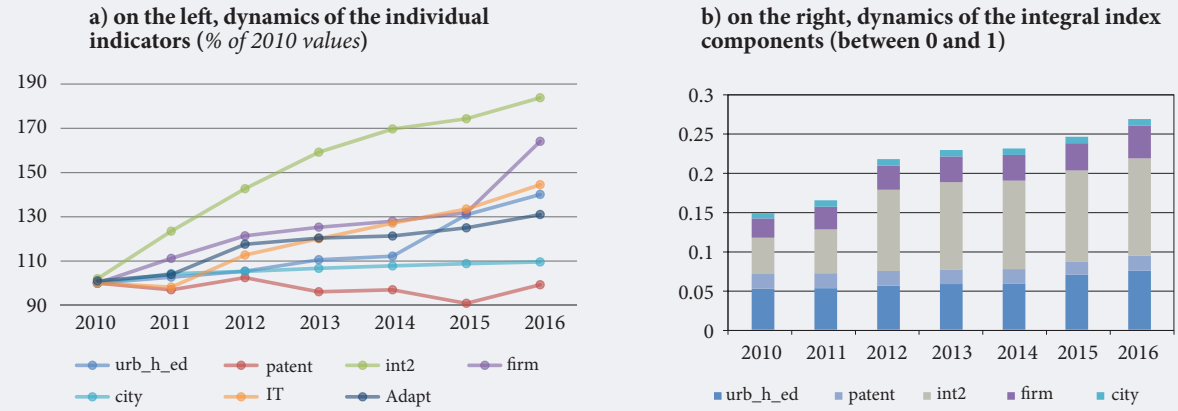
A high share of sectors where manual and routine work operations dominate (such as agriculture and manufacturing) and of the public sector in the regional employment structure does not promote the emergence of new industries.

The identified factors are largely in line with previously described conditions for reducing automation-related risks [*Zemtsov,* 2018]. The obtained estimates help us to better understand the factors that reduce the risks associated with digitalization and those that help actors adapt to this process. Therefore the variables in Table 3 can be used to build a regional adaptation potential index. The ratio of the principle component's variables provided the basis for allocating weights in the integral index, which was calculated using a special toolset. Our experience shows that a small number of indicators not infrequently explains a phenomenon better than indices comprising ten or more components [*Zemtsov et al.,* 2015]. An overabundance of indicators leads to distortion, particularly since many of the former may be unrelated to the phenomenon in question. Accordingly, we propose the following correlation to estimate the integral index:

*adapt=0.23*high_urb_ed+0.16*patent+*
*+0.21*int2+0.15*firm+0.25*city.*

This criterion can be applied to monitor regional development. Even if there are reservations about the quantitative estimates of digitalization-related risks and conditions for the emergence of new industries, knowing the mix of factors that increase the adaptability of the regional economy allows one to trace the dynam-

Figure 5. **Dynamics of Main Indicators Describing Conditions for Regions' Adaptation to Digital Transformation, 2010-2016 (%)**



Note: average values for Russia. See notes to Table 3 for explanation of the variables' designations.
Source: composed by the authors.

ics of adaptive potential and offer recommendations to the local authorities.

Figure 5 presents the dynamics of the main variables and the resulting index since 2010. Conditions for adaptation have improved in all regions, despite the recession during the economic crisis of 2014-2015. Negative trends noted in certain periods only apply to patenting activity. ICT infrastructure showed the highest rate of improvement, which largely determines the dynamics of the overall index (Figure 5 on the right).

The comparison between regional averages (the dark dot in Figure 4) allows one to identify four groups of regions based on the level of automation-related risks and adaptation potential (Figure 6). The territories more attractive to IT professionals are shaded – those where the rate of pay in the sector exceeds the averages for Russia and the relevant region. To successfully adapt to digitalization, regions should not simply retain but also attract human capital.

Group 1: Major urban agglomerations with a diversified tertiary sector: Moscow, St. Petersburg, the Nizhniy Novgorod, Novosibirsk, Samara, Tyumen, and Khabarovsk Regions. Automation-related risks here are lower since industrial production and the service sector that operate on highly competitive markets are already largely automated, while digital transformation is happening naturally. These regions have the most favorable conditions for the emergence of new industries: large and diversified markets (the largest agglomerations in the country), attractive compensation rates (the shaded areas on the map above), and good conditions for doing business [*Barinova et al.*, 2018].

Group 2: Agglomerations where manufacturing industries dominate, but conditions for the emergence of new industries are in place. This group comprises the Rostov, Voronezh, and Omsk Regions, the Republics of Tatarstan and Bashkortostan. They will still have to go through digital transformation, but they are better prepared for it.

Group 3: Far Eastern and Northern regions with limited conditions for automation, such as the Magadan, Murmansk, Archangel, and Amur Regions, Chukotka, Kamchatka, and the Republic of Sakha (Yakutia). Most of these areas have unfavorable conditions for the emergence of new industries due to factors such as the lack of large cities that would provide a dynamic and attractive environment for creative professionals [*Zemtsov et al.*, 2019] and the lack of universities that would train STEAM professionals. This is combined with high business costs and poorly developed ICT infrastructure [*Barinova et al.*, 2018].

Group 4: Regions facing high automation-related risks that have low adaptation potential. This group comprises most of the North Caucasus and Southern Russian regions, a number of areas where manufacturing industries dominate, and the Siberian oil-producing centers. In most such regions, institutional conditions limit the scope for new economic activities and the shadow sector plays a prominent role. In Southern regions the share of rural residents is high and their opportunities to adapt are more limited. New non-routine jobs are not related to STEAM disciplines exclusively: they can emerge in creative industries such as tourism, sports, and entertainment. Southern and Central Russia have rich recreational resources and cultural heritage. For example, the Krasnodar Region, despite the high risks and low adaptation capacity, is attractive to tourists and creative professionals and offers good compensation for IT professionals.

Conclusions and Recommendations

Opportunities for retraining and new job creation in Russia do not match the growing rate of digital transformation. Certain prospects to remain employed are associated with retraining for STEAM professions that

are less vulnerable to the risks of automation. However, not all Russians will be able to retrain, so regions facing high risks of automation should develop relevant adaptation mechanisms in advance. It would make sense to promote entrepreneurship as a good alternative to employment.

The Russian regions' example confirms the mainstream hypotheses about factors reducing digital transformation-related risks put forward by international researchers. Promising conditions for the emergence of new industries, first of all information technologies, exist in areas where a mix of factors are present: major agglomerations, diversified economy, high concentration of human capital, developed ICT infrastructure, attractive entrepreneurial environment, and high innovation potential. In territories with a favorable investment climate for business development (high density of companies, low investment risks, low corruption, etc.) [*Barinova et al.,* 2018] digital transformation may turn out to be less painful.

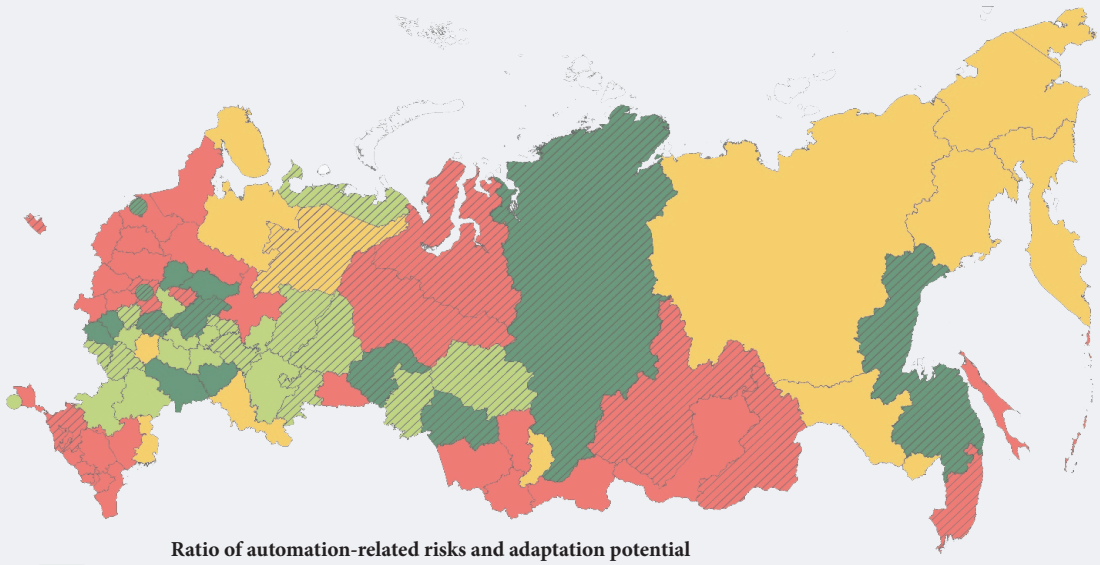
At the same time there are quite a few locations in Russia where automation-related risks are high while opportunities for adaptation are insufficient. This applies to certain North Caucasus republics, southern areas of the Asian part of Russia, and old industrial centers in the northwestern part of the country.

Several global approaches to dealing with digital economy-related problems are suggested [*Vermeulen,* 2018; WEF, 2019]:

- Introducing a robot tax. The revenues could be used to provide social assistance and support to people made redundant by automation. The expected effect will be achieved if this measure is applied internationally.
- Protecting workers' rights. Includes introducing four-day working week or six-hour workday, in line with UN recommendations.
- Introducing universal basic income, which would partly level the uneven distribution of wealth. However, this would involve dealing with the resulting inflation and other issues.
- Encouraging the creation of new companies and involving laid off workers in retraining and obtaining new skills. This is the most suitable option for implementation at the regional and local levels.

Integrated regional digital development programs should be designed[9], specifying adaptation steps to be taken in areas such as normative regulation, the development of information infrastructure, digital economy personnel, and the digitalization of public administration. Such initiatives should include mechanisms for

Figure 6. **Grouping of Regions by Level of Automation-related Risks and Ability to Adapt to Digital Transformation**



Ratio of automation-related risks and adaptation potential

- Group 1: automation-related risks are below the Russian average, while adaptation potential is higher
- Group 2: automation-related risks are above the Russian average, but adaptation potential is higher
- Group 3: automation-related risks are below the Russian average and so is adaptation potential
- Group 4: automation-related risks are higher than the Russian average, while adaptation potential is lower
- Regions where the rate of pay in the IT sector is higher than the Russian average and the average wage in the regional economy

Source: composed by the authors.

[9] Industry-level digital technology development strategies are currently being implemented in the Republic of Tatarstan as well as the Ulyanovsk and Samara Regions.

training highly skilled professionals possessing relevant competences and providing support to high-tech businesses [*Zemtsov et al.,* 2019]. Regions in Group 4 need such adaptation strategies more than others (Figure 6), i.e., those with a high share of manufacturing industries and routine jobs.

The level of human capital in the region directly affects its adaptation potential in the digital age. Therefore R&D, entrepreneurship, creative industries, and STEAM professions should be supported. Acquiring new competences and providing retraining opportunities to the unemployed also contribute to the development of human capital [*Zemtsov et al.,* 2019]. Possible mechanisms include training programs in entrepreneurship, investments in R&D, and the establishment of relevant departments at universities. All such steps would promote cooperation between R&D, education, and the private sector. Setting up entrepreneurial universities favorably affects the emergence of new activities, first of all in the context of encouraging young people to create start-ups. For mature professionals it is recommended to arrange retraining and upgrading courses with the participation of successful companies and initiatives such as WorldSkills.

To extend the range of formats for cooperation between entrepreneurs and offer new self-realization opportunities for people who have been laid off, regional and local authorities may use tools such as coworking sessions, subsidized rents, online services for start-ups, and much more.

The following steps may help make regions look more appealing for skilled professionals and the creative class, they include the careful positioning of the region, the creation of an attractive brand, and advanced city planning policies based on cooperation with recognized urban developers.

Large cities with innovation centers and strong universities can offer a favorable environment for the emergence and growth of high-tech companies. Keeping in mind the huge disparities in Russian regions' capacities [*Zemtsov et al.,* 2019], it would make sense to assume that only some of them would be able to specialize in digital technologies. This ability largely depends upon the level of ICT infrastructure and the rate of applying innovations. Advancing communication potential accelerates the emergence of new industries. Reliable mobile communications and free broadband internet access will help reduce transaction costs and create new markets for start-ups. Building regional entrepreneurial ecosystems would promote cooperation between the relevant players.

The creation of innovative companies in Russian regions was traditionally promoted on the basis of using infrastructure support facilities such as technology parks, special economic zones, and clusters. The development of high-tech sectors in regions requires not only, and not so much, relevant infrastructure (incubators, fab labs, accelerators) as access to markets created by large companies who are also potential customers.

A separate avenue for promoting entrepreneurship is venture capital support and the development of public-private partnerships. Special venture funding programs, technology brokerage, and export consulting are the most important areas for providing support to high-tech companies at the regional level.

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FUTURE SKILLS DEVELOPMENT

Learning to Theorize in a Complex and Changing World

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Abstract

To thrive in the modern world, people need to make sense of complex issues and deal with uncertainty. This requires a different kind of knowledge than schools are teaching. We argue that cultivating a theoretical turn-of-mind is critical for identifying causal relationships and patterns within any phenomenon and trend. In this paper, we introduce a course designed to engage students in an "intellectually honest" version of scientific theory building. We describe four theory-building competencies that students developed as a result of their participation in the course and highlight the features of instruction that may have played a key role in this development. We describe how a particular feature of the course - the theory-building discussion - helped students refine their thinking and we outline the moves the teacher used to facilitate the refinement process. We conclude that learning to construct theories is beneficial even for students who are not tending towards careers in science, as it helps to refine everyday thinking, and, in a broader sense, build human capacities to develop solutions for the complex problems we face across economics, environment, health, and many other domains.

Keywords: theory building competencies; involvement of students; theoretical turn-of-mind; 21st century skills

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Rapid technological development changes every aspect of human activities and increases uncertainty. Efficient strategies in such context rely on non-standard solutions. Thriving in the 21st century requires a different kind of knowledge than schools are teaching. Educators and policy makers need to understand how the world is changing and its implications for what students should learn. Routine jobs are disappearing as robots and computers become more sophisticated. Society and work are becoming ever more complex. If people are not educated to deal with this complexity, they will have a difficult time surviving in modern society. Schools everywhere are anchored in the past. They are teaching a curriculum that mostly dates several decades back. They simply are not preparing youth for the complexity of modern life.

In recent years governments around the world have invested extensive resources in preparing students for careers in science, technology, engineering, and mathematics (the so-called STEM disciplines), because they see them as critical for the future prosperity of their countries. They are the basis for most of the inventions and innovations that are critical to a growing economy. In simpler times before the industrial revolution, people did not need a deep understanding of mathematics and science to make intelligent decisions, but as the complexity of the world has increased, these skills have grown ever more important.

In his book *Introduction to Mathematical Thinking*, Keith Devlin [*Devlin,* 2012, p. 8] notes the two categories of mathematical skills important for a workforce advancing in an industrial society.

- The first category comprises people who, given a mathematical problem, can find its mathematical solution.
- The second category comprises people who can take a new problem, say in manufacturing, identify and describe key features of the problem mathematically, and use that mathematical description to analyze the problem in a precise fashion.

Devlin points out that, as routine work disappears, the need for people with mathematical skills of the first type is diminishing and the need for people with the second type is growing. Devlin's argument can be applied equally well to learning science. To thrive in the modern world of work, it is critical to be able to analyze problems, identify the elements and patterns comprising their deeper structure, and develop explanations for their causes in order to find workable solutions. These capacities are important aspects of scientific theory building. We therefore argue that it is critical for our students to develop theory-building skills.

Theory is central to science [*Suppe,* 1974, p. 3] and plays a powerful role in the development of technology [*diSessa,* 1991, p. 229]. Students should engage in theory building in order to learn elements of its associated practices and cultivate a theoretical turn-of-mind. Such engagement may also promote more nuanced perspectives on the nature of science and foster students' sense of epistemic agency. Despite its importance to science, theory building has been relatively underemphasized in the science classroom as compared with empirical investigation. Recently in the US, science educators have begun to focus on some aspects of theory building, such as modeling and explanation. However, these aspects do not capture the full range of theory-building practices.

To prepare our future scientists and foster the sense-making skills necessary for all students to navigate the complex challenges of the 21st century, educators need to articulate a broader category of theory-building practices and offer students opportunities to engage in them in meaningful ways in school. In this paper, we introduce a course that engaged students in an "intellectually honest" [*Bruner,* 1977] version of scientific theory building. We describe four theory-building competencies that students developed as a result of their participation in the course and highlight the features of instruction that may have played a key role in their development. We describe how a particular activity - the theory-building discussion - helped students refine their thinking and we outline the moves the teacher used to facilitate the refinement process. Finally, we consider the implications of our research findings for educating our future scientists and more broadly, citizens prepared to thrive in a complex and changing world.

A Theory-Building Course

According to Einstein, "The whole of science is nothing more than a refinement of everyday thinking" [*Einstein,* 1936]. This conveys the constructivist perspective on learning, where a learner builds formal knowledge by reorganizing and refining their prior knowledge [*Smith et al.,* 1994]. The course was designed to help students refine their thinking through theory invention, test, and revision.

The course focused students on building theories about patterns in system behaviors (including threshold and equilibration) that can be seen in examples across domains, from physical to psychosocial. Threshold, for example, can be seen in the tipping point of a tower of blocks and the limit of a person's patience. Both phenomena exemplify a pattern of *pre-phase, limit, and reaction*, where a parameter is varied during a *pre-phase* until a *limit* is exceeded and the system *reacts* by making an irreversible transition to a new state. Equilibration can be seen in a glass of cold water warming to room temperature and the calming of a person's emotions. Both phenomena exemplify a pattern of *difference drives rate* where a system tends toward equilibrium quickly at first, and then more slowly as it approaches that state. Patterns like threshold and equilibration are concerned with the behavior underlying phenomena, or their *deeper structure*. Such patterns often capture causal relationships between events, and therefore have *explanatory power*. They are exemplified by many

Table 1. **The Framework of the Theory Building Course**

Unit	Longevity (hours)	Contents
Introductory	6	Introducing abstraction
Threshold	10	Articulating deeper structure and determining a threshold pattern
Equilibration	20	Articulating causal relationships and determining an equilibration pattern
Practice	16	Studying exponential growth and oscillation, practicing abstraction, articulating deeper structure, and articulating causal relationships

Source: compiled by the authors.

phenomena and are therefore best articulated in general terms, as *abstract* constructs.

These qualities make patterns a good target for theory building in the science classroom, as scientific theories are meant to convey the deeper structure underlying a class of phenomena [*Toulmin,* 1958; *Hempel,* 1974], to explain those phenomena [*Hempel, Oppenheim,* 1948], and to be abstract, so as to apply to a broad range of phenomena [*Atkins,* 2010]. Further, patterns can be explored through many different phenomena, so students can generate their own examples and construct their theories in contexts where they have some expertise. Though their pattern theories may vary in the degree to which they achieve deeper structure, explanatory power, and abstractness, all students can succeed at generating an initial theory, and all students can improve their theories by thinking about their own and their peers' ideas more carefully [*Swanson,* in press]. The theory-building course was tested and refined as part of a larger effort to understand middle school students' intuitions about patterns and how these intuitions could be leveraged by classroom instruction to help the students construct concepts of dynamical systems theory. Dynamical systems theory is a powerful framework used by scientists across domains to model processes of change and control [*Devaney,* 1992].

The course was implemented at a public middle school located in an economically depressed neighborhood of a large city in the western United States. The school was selected based on the willingness of the 8th grade science teacher to share her elective class with our research team. The first author taught the course, having been a high school science teacher for six years before transitioning to research. She arranged to teach the course with the intention of explicitly cultivating a classroom culture that would support students in sharing, making sense of, and refining their everyday thinking. Twenty-one 8th grade students (11 girls and 10 boys) participated in the course. Eighteen of the students had immigrated with their families to the US from Mexico and Central America. Two students identified as African American and one as Bosnian American. English was a second language for most students, Spanish being their primary language. The majority of students attending the school were designated as English Language Learners from low-income households. The students were selected on the basis of their availability and willingness to participate in the experimental curriculum.

The course staged the introduction of different tasks that comprised the pattern theory-building process. These included:

- describing the behavior underlying a single phenomenon (i.e., articulating deeper structure),
- explaining the cause of the behavior (i.e., articulating causal relationships), and
- generalizing the theory by articulating the elements of deeper structure common to multiple phenomena (i.e., abstraction).

The general framework of the course is presented in Table 1.

The course was implemented over an entire school year. The class met three mornings a week for 40 minutes, for a total of 52 hours of instruction. Students constructed theories of patterns exemplified by everyday phenomena, including patterns of threshold, equilibration, exponential growth, and oscillation. Pattern units were interspersed with lessons focused on how building pattern theories related to theory building in science.

For each unit, students individually constructed theories through an iterative cycle involving steps of generation, test, and refinement. They created a first draft of their theory after exploring two phenomena (provided by the teacher), which exemplified the pattern the teacher had in mind. They tested their nascent theory on a third example (also provided by the teacher) and then refined their ideas, producing a second draft of their theory. They generated a list of phenomena that exemplified the pattern and tested how well their theories fit these examples. They then refined their ideas, producing a third and final draft of their theory. Though the students were encouraged to build theories for the patterns that were salient to them, they were nudged in the direction of canonical conceptualizations of threshold, equilibration, exponential growth, and oscillation, as these were powerful for understanding concepts in dynamical systems theory. The teacher accomplished this by selecting particular exemplars and bringing the students' attention to productive ideas that were shared by students during class discussions.

Students wrote their theories individually but were encouraged to share their ideas with their classmates. In all cases where students generated theories, they first worked alone and then shared their ideas once they had produced a draft. This was to create a space where students could carefully consider their own ideas and articulate them before exposing them to the critical review of their classmates. The 21 students were distributed across six tables and were randomly assigned their seats at the beginning of each month. When they investigated examples, they worked with one of their tablemates (except for a group of three, which worked together). When they created group artifacts such as posters, they worked with all students at their table.

Introducing Abstraction

Students were introduced to *abstraction* in an introductory unit. They were first introduced to the words *general* and *specific*. Students then practiced abstraction by creating and refining definitions for a general category that included chocolate chip cookies, oatmeal raisin cookies, graham crackers, Oreos, and other "objects" of the students' choice. The teacher led students in reflecting on their process with the intention of helping them see where they were engaged in abstraction (although they were never introduced to this term) by describing *general* features that were common to many *specific* examples.

Introducing Deeper Structure

Students were introduced to describing *deeper structure* in the context of a unit on threshold. A canonical conceptualization of threshold (as a pattern of *prephase*, *limit*, and *reaction*) guided the teacher's selection of exemplars. The unit guided students through the exploration of exemplary phenomena and the generation, test, and refinement of their own descriptions of the pattern they found across examples.

The unit opened with investigations of two threshold exemplars. The first was a challenge to see who could hang the most pennies from a spaghetti bridge. The second was a challenge to balance the greatest number of water droplets on a coin. The two examples were meant to complement each other because both examples featured coins. This similarity could illuminate whether students attended to common deeper structure or surface features and illustrate that what was meant by "pattern" was *behavior* common to both examples, rather than similarities in the objects they featured (such as coins). For both challenges, the students individually wrote descriptions and drew pictures of the behavior they had observed.

Following their exploration of the two examples, the students generated a first draft theory of the pattern they thought both examples followed. Their work was guided by the prompt: "Describe the pattern that the specific behaviors follow. One trick for doing this is to start by telling the story of both behaviors so that someone listening to your story would agree that you are talking about either one of the behaviors, but they wouldn't know for sure which one you were talking about." The prompt directed students to focus on the deeper structure behavior the examples had in common, as opposed to similarities in surface features. It also emphasized that the theory should be abstract, omitting the features that would tie it to either phenomenon.

Next, the students tested their theories against another exemplar: the addition of salt (one spoonful at a time) to a cup of water until a submerged egg floated to the water's surface. They were then invited to revise their thinking and write second drafts of their pattern theories. Following this, they generated their own list of pattern examples and then argued about whether or not these examples followed the pattern in the context of a whole-class debate. Following the debate, students were invited to revise their thinking a final time and write third drafts of their pattern theories.

Introducing Causal Relationships

Students were introduced to articulating a *cause for a behavior* in the context of a unit on a pattern of equilibration. This was a pattern of *difference drives rate*, where the rate of a system's equilibration is directly proportional to its distance from its equilibrium state. The unit followed the same basic structure as the threshold unit; however, a great deal of time was given to engaging students in crafting causal explanations for the behavior underlying each example.

The unit opened with investigations of two equilibration examples. The first investigation was on the rate at which a glass of cold water warmed to room temperature. The example illustrates *difference drives rate* because, when the temperature of the cold water is farthest from that of the room, the cold water warms fastest. This pattern is essentially Newton's law of heating. Students interpreted the data and noted that the temperature changed over time "fast and then slow." They individually generated explanations for this pattern and discussed their ideas in the context of a whole-class theory-building discussion, which was meant to cultivate their capacity for articulating causal relationships in phenomena [*Swanson, Collins,* 2018].

The second example focused on the rate a glass of hot water cooled to room temperature and followed the same sequence as the cold water example. The students discussed the behavior exhibited by both cold and hot water examples and then generated initial theories for the pattern both examples followed. They wrote their theories in response to the same writing prompt as the threshold unit.

Next, they explored a third phenomenon that exemplified the pattern: particle diffusion. They simulated particle diffusion using a partitioned box that was filled on one side with two tablespoons of dried beans, shaking the box back and forth along the table so the beans moved in both directions through a small gap in the middle of the partition. In this example, the *dif-*

Table 2. **Aligning Students' Pattern Theories with Canonical Scientific Conceptualizations**

Unit	Canonical scientific conceptualization
Threshold	Pattern of pre-phase, limit, and reaction
Equilibration	Difference drives rate

Source: compiled by the authors.

ference between the number of beans on either side of the box *drives the rate* of the redistribution of beans. After recognizing the fast-and-then-slow pattern in the data, students wrote down causal explanations for the change in rate and then engaged in a brief theory-building discussion.

The students discussed how this example compared to the previous two examples and their previous pattern theories. They then wrote second drafts of their pattern theories. As in the threshold unit, they generated their own list of pattern examples and then argued about whether or not these examples followed the pattern in the context of a whole-class debate. They then wrote third drafts of their pattern theories.

We analyzed students' written theories and video footage of their class discussions using both qualitative and quantitative approaches. We found that students developed competencies for theory building and refined their everyday thinking to develop a deep scientific understanding [*Swanson*, in press]. We describe these findings and speculate on features of the course that may have fostered these learning outcomes.

Cultivating a Theoretical Turn-of-Mind

For both threshold and equilibration units, the students built abstract theories of the deeper pattern of behavior common to the examples they explored. Their work can be seen as existing on a continuum with the work of scientists. Below, we introduce four theory-building competencies the students demonstrated through their participation in the course. These are: 1) attention to empirical validity and completeness, 2) articulating deeper structure, 3) articulating causal relationships, and 4) abstraction. In our research, we found that participation in the theory-building course helped students develop these competencies and thereby cultivate a theoretical turn-of-mind [*Swanson*, in press].

Attention to Empirical Validity and Completeness

Scientific theories are evaluated with respect to their validity and completeness. We characterize the validity of a theory as the degree to which it corresponds with empirical observations [*Wilensky, Rand,* 2007], and its completeness as the extent to which it includes aspects that are consequential to explaining and predicting the phenomena to which it applies. In the patterns course, these competencies were operationalized together as the degree to which students' pattern theories aligned with canonical scientific conceptualizations (Table 2).

Our research showed that over the three drafts, students refined their everyday thinking into theories of threshold and equilibration that aligned better with the canonical scientific conceptualizations [*Swanson,* in press]. The key statistical data representing the evolution of learning process are reflected in Table 3.

The students gradually refined their ideas toward the scientific conceptualizations of threshold and equilibration through a process that was guided by the structure of the course. The main steps of process were having students articulate their ideas, consider one another's ideas, and engage in making sense of those ideas. Activities that elicited students' ideas included asking students to write down their pattern theory and share the pattern they had identified, or a possible causal explanation for a particular phenomenon. Activities that showcased ideas for students to consider included poster presentations, gallery walks [*Kolodner*, 2003], and writing ideas on the board. Activities that engaged students in making sense of one another's ideas included whole-class theory-building discussions and pattern-example debates, during which the teacher asked students to evaluate, justify, challenge, or elaborate each other's ideas. For both pattern units, the refinement process moved back and forth between individual and group work, giving students time to think on their own and then engage in collaborative sense-making.

Articulating a Deeper Structure

Scientific theories are concerned with articulating the form of empirical regularities [*Toulmin,* 1958] and the processes that underlie them [*Hempel,* 1974]. These can be thought of as deeper structure. The ability to look beyond the surface features of a phenomenon and articulate deeper structure is a hallmark of expertise in science [*Chi et al.,* 1981] and is fundamental to the

Table 3. **Evolution of the Students' Theories over the Course**

Unit	Initial formulations	Finite formulations
Threshold	Over half of the students wrote theories that focused on surface features or included only one of the three elements – *pre-phase, limit,* or *reaction*.	Fifty percent had refined their theories to include all three elements of pre-phase, limit, and reaction (e.g., "Repeating a process till something happens"); Thirty percent had refined their theories to include two of the three elements (e.g., "Adding or taking something away till it reaches the maximum").
Equilibration	Over half of the students wrote theories that focused solely on changing rate (e.g., "The pattern went fast and then slow").	Sixty five percent had refined their theories to align with difference drives rate (e.g., "There is a larger distance, so it goes fast. There is less space, so it goes slow. No more space, so it stops.").

Source: compiled by the authors.

construction of scientific theories. Deeper structure was operationalized in the context of students' pattern theories as a description of the *behavior* exemplified by a phenomenon (e.g., "Adding something to something until it changes"), as opposed to a description of its context-specific features (e.g., "Both used household objects"). The theory-building course guided students to look for the deeper dynamic interactions or relational structures [*Gentner*, 1983] exemplified by multiple phenomena, rather than similarities in their surface features.

Our research findings showed that, from the start of the threshold unit to the end of the equilibration unit, students improved their theories by removing surface features and shifting their focus to articulating the deeper pattern in behavior [*Swanson,* in press]. For example, at the beginning of the threshold unit, about three-quarters of the students described surface features the spaghetti bridge and drops-on-a-coin investigations had in common (e.g., "We used pennies in both of them"), and about three-quarters of the students included elements of deeper structure.[1] By the end of the equilibration unit, all students' theories focused on deeper structure (e.g., "The space is greater at first, which makes it go fast, then it slows down as the amount of space decreases"), and only 10% referred to surface features.

For both threshold and equilibration units, students began by exploring two examples that were near analogies (i.e., threshold: adding objects to container objects until they broke; equilibration: warming and cooling liquids). They identified the pattern based on the first two examples and then tested their pattern theory on a third example, which was more analogically distant (i.e., threshold: adding salt to water until an egg floated; equilibration: particle diffusion across a semi-permeable boundary). It is possible that working with the near examples helped students identify the relational structure, that knowing this relational structure helped them see it in the third example and the later ones they invented. In her research on analogy, Gentner found that giving novices two closely related examples (examples that matched both in terms of relational structure and surface features) helped them identify relational structure in those examples. Novices were then more likely to notice the relational structure in a more distant example [*Gentner*, 1983]. Gentner gave the name *progressive alignment* to the process of helping students find relational structure in more distantly analogous examples by having them first identify the relational structure in near examples [*Loewenstein, Gentner,* 2001].

Articulating Causal Relationships

A chief application of scientific theory is the explanation of empirical phenomena [*Hempel, Oppenheim,* 1948]. A scientist must therefore be able to articulate causal relationships within a phenomenon that might explain it. For example, the modern, differential equation form of Newton's law of heating expresses the proportional relationship between an object's rate of temperature change and the difference between its temperature and that of its environment as $dT/dt = k(T_{env.} - T_{obj.})$. Physicists regard the temperature difference on the right-hand-side of the equation as a "thermodynamic driving force" that influences the rate of temperature change on the left-hand-side of the equation [*diSessa,* 2014, p. 806]. We therefore consider this (and similar relationships captured by other abstract mathematical models) to be a scientifically legitimate form of causality. The theory-building course guided students to first describe the behavior they perceived in multiple phenomena and then conjecture the cause of that behavior.

Our research findings showed that students began to articulate causal relationships in their theories during the equilibration unit and that they improved with respect to this over its course [*Swanson,* in press]. All theories produced during the threshold unit focused on describing the pattern in behavior, as did all of the first draft equilibration theories. By the end of the equilibration unit, two-thirds of the theories sought to explain the cause of the pattern in behavior (e.g., "Fast because there is more space to cover and it slows down because every time less space is available and with less space it can slow down").

The feature of the course that supported students' development of this skill was the theory-building discussion [*Swanson, Collins,* 2018], during which the students worked collaboratively to build a causal explanation for a particular pattern phenomenon. Their first discussion focused on the first equilibration exemplar: a glass of cold water that warmed to room temperature "fast and then slow." They engaged in similar discussions for the second (hot tea cooling) and third (shaking beans-in-a-box) examples, as well. The theory-building discussion brought students' attention to the *causal* elements of the underlying relational structure of each example. According to Gentner and Colhoun [*Gentner, Colhoun,* 2010], looking for causal relationships is a natural tendency: "In analogical matching, people are not interested in isolated coincidental matches; rather, they seek causal and logical connections, which give analogy its inferential power." The theory-building discussion therefore supported students' natural tendency to look for causal relationships and build explanations.

Abstraction

The usefulness of a scientific theory, in part, depends on its range of applicability [*Atkins,* 2010]. For this reason, scientific theories are articulated in ways that render them general and more broadly applicable [*Suppe,* 1972; *Toulmin,* 1958]. Drawing on von Glasersfeld [*von*

[1] Theories could contain both surface features and elements of a deeper structure.

Table 4. **Pedagogical Moves Used within the Course**

Aim	Impacts
Eliciting student ideas	Drawing out students' knowledge by asking them to articulate their ideas and unpack their reasoning. Eliciting moves sparked creative thinking and guided students to generate the raw material they would ultimately refine into more formal knowledge over the course of the discussion.
Showcasing student ideas	Creating shared artifacts on which the community could reflect and out of which they could refine their shared explanation. Some of the moves created momentary artifacts (e.g., verbal restatements) while others created more permanent artifacts (e.g., writing ideas on the board).
Engaging students in making sense of ideas	Helping students consider their classmates' ideas more carefully. These moves sometimes led to the production of new ideas (by sparking creative thinking); however, their most important function was the modification of existing ideas (by facilitating critical thinking).
Helping students locate themselves within a broader landscape	Pointing out how their discussion built on prior lessons, and how it was building toward lesson goals. These moves were meant to help students gain perspective on the dynamics of the discussion *process* as opposed to the meaning of its *content*. Given that these moves illuminate the process of knowledge construction, they are meant to promote a kind of metacognition.
Framing students as agents of scientific knowledge construction	Encouraging students' participation by elevating the status of their meaning-making activities and respecting their ideas as valuable contributions to the process. These moves were also meant to give students a sense for the theoretical half of the scientific enterprise, in particular the role of human creativity in constructing and evaluating knowledge.
Fostering equitable participation	Cultivating an environment in which participation was expected, promoted, made safe, and supported by both encouraging and corrective feedback.

Source: compiled by the authors.

Glasersfeld, 1991], abstraction is a process of drawing out "general ideas from experience" and "substituting a kind of place-holder or variable for some of the properties in the sensory complex we have abstracted from our experiences of particular things." Evidence of abstraction is identified in students' theories as the use of general or context-free language (e.g., "Goes fast then slow, eventually stops"), as opposed to context-specific language (e.g., "Goes slow to reach maximum room temperature"). In the patterns course, students were encouraged to use general language so that their theories could be applied to phenomena across domains.

Our research showed that over the course of both units, students' theories became more abstract [*Swanson,* in press]. Students accomplished this by decreasing their use of specific language and by increasing their use of general language. This means that over time, fewer students described the pattern in the context of a particular phenomenon (e.g., "We used pennies, we put the pennies in a container, we counted, we did it again") and more students described the pattern without referencing any particular phenomenon (e.g., "In a large distance it goes fast then when the space gets smaller it goes slow. Then when there's no more space it stops.").

It is likely that their consideration of many different examples played a key role in helping students create general theories. As their theory had to expand to include more and more distant examples, elements of surface-features common to previous, near-analogy examples would have to be removed. This can be seen in threshold, where one student's initial pattern theory (that was general to the spaghetti bridge and drops-on-a-coin example) had to be revised from containing a *reaction* of "destroyed" to one of "changed," in order to include the third example, where the egg is not destroyed but rather, floats. Gick and Holyoak (1983) called the process of abstracting a common "core idea" from multiple analogs "schema induction." They conjectured that schema induction involved "deleting the differences between the analogs while preserving their commonalities" [*Gick, Holyoak,* 1983, p. 8]. In their research, they found that subjects struggled to derive schemas given a single analog, but given two analogs, they succeeded.

Refining Everyday Thinking

Our research has shown that the course helped students refine their everyday thinking into more scientific thinking. One activity seems to have played a particularly important role in this development: the theory-building discussion [*Swanson, Collins,* 2018]. Students began one such discussion by investigating the rate of temperature change over time for a glass of cold water as it warmed to room temperature. They used computer software to collect data for temperature over time as ice water warmed to room temperature. Following the investigation, they interpreted the data and described the temperature change over time as "fast and then slow." They then individually generated explanations for this pattern. Their explanations served as the basis for a class-wide theory-building discussion, through which the teacher facilitated their collaborative refinement of a causal explanation for the pattern.

Students began the discussion with idiosyncratic ideas about the temperature of the water "slowing to a stop" like a runner slowing to avoid crashing into a wall, and the temperature increasing quickly at the start because it was far away from the wall and therefore safe to go fast. Gradually, through guided discussion, the teacher helped students refine their ideas into a *difference drives rate* explanation reflective of Newton's law of

heating [*Swanson, Collins,* 2018]. In our analysis, we found that the teacher guided students' articulation and refinement of ideas through moves that elicited, showcased, and engaged students in making sense of their ideas. She facilitated the discussion more generally through moves meant to help students locate themselves within the broader landscape of their learning, to frame students as agents of scientific knowledge construction, and to foster equitable participation. The characteristics of the pedagogical moves are summarized at Table 4.

Conclusion

In this paper, we introduced a course designed to engage middle school students in an "intellectually honest" version of scientific theory building. We discussed four theory-building competencies that students developed as a result of their engagement in the course and considered the features of instruction that may have helped cultivate these competencies.

Our work demonstrates that students can engage in aspects of scientific theory building and that, with the support of instruction, they can develop skills for participating in the practice. These findings challenge commonly held assumptions about the developmental capacities of young learners regarding both the identification of deeper structure and abstraction [*Chi et al.,* 1981; *Larkin,* 1983]. We have also shown that the theory-building process helps students develop a deep understanding of scientific content through a process that mirrors that of scientific knowledge construction. By eliciting students' ideas and engaging them in making sense of their own and their classmates' ideas, the theory-building approach guides students to refine their everyday thinking. Theory building offers a constructivist approach to classroom instruction that productively leverages the prior knowledge students bring to their learning.

We argue that theory building in the science classroom offers benefits beyond the development of skills and content knowledge. It exposes students to a more authentic version of science as it is practiced by professionals. This gives them a more nuanced perspective on the nature of science and a sense for the role of human creativity in the development of scientific knowledge. It paints the development of scientific knowledge as a *constructive* process, rather than a process of *discovery*. This dispels the authority of scientists and received scientific knowledge, giving students a sense of agency and opening the possibility that they might one day contribute to the broader scientific discourse.

It seems particularly important, in working with students from historically marginalized groups, to give them a sense that they can take part in creating and challenging scientific knowledge. Positioning students as creators and evaluators of scientific knowledge can create a more inclusive experience of science by broadening "the content and form of science knowledge valued and communicated through education" [*Bang et al.,* 2012, p. 304]. By honoring the everyday thinking students bring to their learning [*Warren et al.,* 2001] and challenging the authority of received scientific knowledge [*Bang, Medin,* 2010], the approach works toward the objectives, shared by many teachers, to cultivate classrooms that are more inclusive and equitable. Instruction that honors learners' individual ways of thinking invites diverse perspectives to the construction of scientific knowledge, promotes the heterogeneity of ideas, and cultivates a healthy ecosystem for science. As Feyerabend [*Feyerabend,* 1993, p. 24] said: "Proliferation of theories is beneficial for science, while uniformity impairs its critical power."

From a social perspective, helping students cultivate a theoretical turn-of-mind is crucial. Society is faced with many problems, such as obesity, pollution, economic bubbles, and technological addiction. These are challenging issues that must be addressed with a different kind of thinking than the thinking that created them. It is imperative for education to focus much more on teaching students how to think critically and make sense of the complex problems that arise in life [*Collins,* 2017]. Developing creative and sustainable solutions requires understanding the deeper patterns and causal relationships that underlie complex phenomena. By helping students cultivate a theoretical turn-of-mind, we can prepare them to address the challenges of our complex and changing world.

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The Role of Human Capital in Science, Technology and Innovation

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Abstract

As a result of the transformation of the labor market, the constant development of human capital has become crucial. This paper considers the role of human capital in professional development through the prism of 16 semi-structured interviews with both Russian and foreign graduates of a master's program focused on training experts in the field of science, technology, and innovation. Most of the graduates of the program found jobs in the corporate sector and at research centers, but among the interviewees, there were also representatives who chose self-employment or public service. The contribution of undergraduate and master's degrees to the professional development of these interviewees was assessed and they noted that if studying at the undergraduate level contributed primarily to obtaining subject knowledge, then studying at the master's level contributed to the development of missing competencies and the opening of new professional opportunities. Interviewees identified emotional and social intelligence as key skills in their professional development and noted the critical importance of digital skills and subject knowledge. In turn, the most popular way of training, in the opinion of respondents, is online education.

Keywords:
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The rapid technological development of the recent decades brings to the forefront the need to achieve the sustainable growth of the innovative knowledge-based economy [OECD, 2017]. This, in its turn, requires specific professional competences and a high level of skills [*Karnouskos,* 2017]. Workers possessing them will play a key role on the labor market, since companies' innovation development and countries' competitiveness ultimately depend on them [*Burmann et al.,* 2018].

At the same time, digitalization transforms the labor market too [*Kapeliushnikov,* 2017]. For example, there is a more than 50% probability that about a half of all jobs in OECD countries will be significantly automated, which will change skill requirements [*Nedelkoska, Quintini,* 2018]. Employers estimate that the further development of technologies and business models will make 42% of the currently applied skills totally irrelevant as early as 2022 [WEF, 2018]. Accordingly, along with the emergence of new jobs that would require unique skill sets to accomplish previously non-existent tasks, conventional jobs will also require new, unorthodox approaches [HSE, 2018].

Against the background of the digital transformation of businesses, the changing requirements for workers' competences create the need for their continuous upgrading. As a recent survey of training and upgrading professionals demonstrated, 80% of companies believed this was a priority [*Thomson et al.,* 2017]. However, volatile, uncertain, complex, and ambiguous (VUCA) business conditions make training staff on new skills which are not only relevant here and now but would also remain so in the future, a much more complex task [*Horstmeyer,* 2018]. The competence profiles that specific companies require are being constantly adapted to match the changing environment, hard-to-predict developments, increasingly complex business processes, and their interaction with each other [*Horney et al.,* 2010]. Demand for design thinking is growing, which implies a systemic approach to problems and finding solutions for them, the ability to suggest different approaches to a task, visualize and explain one's ideas, and effectively communicate with professionals specializing in different subject areas [*Razzouk, Shute,* 2012].

To increase their professional value on the rapidly changing labor market, workers need to constantly increase their human capital [NAFI, 2017] which comprises specific specialized knowledge and skills in which education plays the key role [*Biriukova et al.,* 2018]. Employers see formal qualifications as a guarantee that a worker has certain competences, which can be extended by subsequent training and retraining. This resource for developing human capital allows one to transfer the most sought-after professional skills to workers and increase their productivity [*Gimpelson et al.,* 2017].

The goal of this paper is to define the role that human capital plays in the professional development of young workers specializing in the science, technology, and innovation (STI) sphere during the first few years following the completion of their formal education. Sixteen semi-structured interviews with 2016-2018 graduates of the STI governance Master's program (ISCED 7 level) provided the empirical basis of the study. The respondents represented four career paths (tracks): most of them were employed in the corporate sector or by R&D centers, plus young entrepreneurs and civil servants. The study's methodology was based on the qualitative analysis of various components of the Global Human Capital Index developed by the World Economic Forum (WEF).

Literature Review

The term "human capital" suggested by Theodore Schultz [*Schultz,* 1961] is defined as the sum of workers' knowledge and skills that have economic value and increase productivity. Sometimes not only knowledge and skills, but natural abilities and experience are also seen as elements of human capital [*Bontis,* 1999]. Gary Becker [*Becker,* 1994] made an important contribution: he focused on education and training (upgrading) as the key factors for increasing human capital. Becker's study distinguishes between *basic training* at work over the course of which people learn skills that can be applied at other companies or in different industries, and *specific* training largely relevant for a particular company or a narrow activity area. He also suggested a model to empirically assess the economic efficiency of education as an investment in human capital.

The WEF's Global Human Capital Index provides one of the most comprehensive modern assessments of education's impact on human capital quality [WEF, 2017]. The index takes into account only skills that can be seen as a dynamic assets which develop with time, as opposed to innate abilities. The global index in question comprises four key subindices which reflect the level of human capital, its applicability and development, and the mastery of specific skills and competences [WEF, 2017]:

- *Capacity*: measures the value of formal education; the higher it is, the quicker new technologies can be adapted, and innovations applied to increase the country's global competitiveness;
- *Deployment*: is related to the application of the accumulated human capital at work, and its further increase over the course of training, professional activities, and informal exchanges of knowledge and best practices with colleagues;
- *Development*: applied to evaluate the prospects for the future development of human capital through formal education, including upgrading and retraining over the course of life-long learning;

- *Know-how*: measures the scope and level of specialized skills required for professional activities.

The OECD [OECD, 2005] identifies three key skill groups: (1) the ability to act on one's own (planning, substantiating one's position) or (2) as a member of a diverse team (teamwork, conflict management), and (3) the mastery of various tools, i.e., the ability to interactively use basic (such as reading, writing, etc.) and more advanced communication tools (information and communication technology, ICT). The international project "The Assessment and Teaching of Twenty-First Century Skills" identified four groups of such competences: those related to thinking (critical, creative), interaction (communication and collaboration), work (digital literacy), and life (responsibility, cultural awareness) [*Binkley et al.,* 2012]. Both these classifications are primarily focused on broadly understood skills required to achieve personal, social, and economic wellbeing as opposed to subject-specific knowledge which frequently cannot be applied after it was learned [*Collet et al.,* 2014]. In other words, the 21st century competences have more to do with processing information than with possessing it.

[*Pellegrino, Hilton,* 2012] break down the 21st century competences into three major clusters: cognitive, interpersonal, and personal ones. In the first group, they include digital and research skills along with critical thinking. The interpersonal skills group comprises teamwork and leadership. Personal skills include self-control, self-assessment, and an open mentality. Other well-known classifications [*Collet et al.,* 2014] seem to be quite similar to the aforementioned one. Various Russian experts also agree that the 2025 competence goal model should comprise three clusters: cognitive, socio-behavioral, and digital skills [*Butenko et al.,* 2017].

The above competency clusters comprise universal metaskills applicable in various areas [*Finch et al.,* 2013] and among those relevant for the technology and innovation sphere [*Collet et al.,* 2014]. Detailed competency lists drafted by international organizations, various research teams, or individual scientists tend to be excessively heterogenous in terms of grouping and the level of detail. Like [*Karnouskos,* 2017], we identified six major clusters, each comprising two main skill groups: research and digital skills in the cognitive competences cluster, intercultural awareness and social intelligence in the interpersonal one, and emotional intelligence and interdisciplinarity in the personal competences cluster.

Research skills traditionally play the key role in higher education. Having them, along with the ability to use them, are seen as key characteristics of university graduates, especially those at research universities [*Garg et al.*, 2018]. However, though these skills are frequently learned by taking part in research, the scope for their subsequent application is much wider than that [EuroDoc, 2018], since "research" as such is not necessarily limited to generating completely new knowledge. It also includes collecting information previously unknown to specific persons, or new in a specific context [*Willison, O'Regan,* 2007].

Basic research competences include the ability to clearly see which results should be achieved while accomplishing a specific task, the ability to find or generate new knowledge using relevant methodologies, and the ability to assess the collected information, manage it, organize, analyze, structure, discuss, and use it in the course of subsequent work [*Willison, O'Regan,* 2015]. Outside the R&D sphere, these skills can be easily transformed into others, which makes research programs' graduates highly employable (employability skills). Acquiring research competences in the course of one's education allows one to [*Bandaranaike,* 2018]:

- clearly understand one's work responsibilities and project objectives;
- identify resources and technologies required to accomplish work-related tasks;
- assess the level of one's skills and maintain it throughout one's career;
- organize one's professional activities;
- apply creative and critical approaches to problem solving;
- efficiently interact with the professional community.

The digital revolution has led to technologies' penetrating all spheres of life. As International Telecommunication Union (ITU) experts note, in effect any professional activity now requires one to have at least a basic level of digital skills [ITU, 2018], which increasingly often are seen as fundamental and universal ones (along with reading, writing, and arithmetic). However, apart from the basic level, experts identify two more levels of these skills: intermediary (ability to accomplish professional tasks such as, e.g., graphics design or digital marketing) and advanced ones (in the ICT context, this is first of all programming). As demand for digital competences grows, universities pay increasingly more attention to teaching them. For example [*Oliver, Jorre,* 2018] note that in 2015, Australian universities mentioned digital literacy skills among the results of the education they provide 14% more often. In October 2018, the pilot European survey of graduates was launched in the EU (EUROGRADUATE), in the scope of which the respondents were asked to assess how their digital skills matched employers' requirements [*Meng,* 2018].

The globalization of the labor market, along with growing professional mobility has led to the increasingly active interaction between people of various nationalities, cultures, ethnic groups, and religions, especially in global competency centers [*Huber,* 2012]. Intercultural awareness is necessary for such

interaction, which helps workers accept other people's values, traditions, and convictions – which in turn helps avoid possible misunderstandings between project participants [*Zhu,* 2011]. Such intercultural awareness elements as respect, tolerance, caring, interest in, and attention to others [*Cukier et al.,* 2015] make it possible for people to efficiently work alongside each other in the present-day multicultural, multinational environment.

Employers also have demand for such university graduates' traits as social intelligence, i.e., the ability to participate in social interaction, cooperate, establish productive social relations, build trust with colleagues, reach understanding, and share information and ideas [*Gkonou, Mercer,* 2017]. According to the classic definition by Edward Thorndike [*Thorndike,* 1920], social intelligence represents the mental ability to understand and manage relations with other people, regardless of their gender and age. An important component is effective behavior, i.e., the ability to establish relations with counterparts in various situations [*Ford, Tisak,* 1983] and "inspire others to behave effectively" as a basis for leadership [*Goleman, Boyatzis,* 2008].

The ability to be aware of one's own emotions, manage them, and move on towards a desired goal in line with one's beliefs and motivation is at the core of emotional intelligence [*Salovey, Mayer,* 1990; *Goleman,* 1995]. Though some researchers also include in this group the ability to recognize other people's emotions, unlike social intelligence, which is focused on interaction and cooperation, the emotional one is primarily about people's personal state and perceptions [*Gkonou, Mercer,* 2017]. In other words, social intelligence can be seen as an extension of the emotional one [*Goleman, Boyatzis,* 2008], though it is the latter which is frequently considered a key competence highly skilled workers are expected to have [*Mayer et al.,* 2008].

Surveys show that for employers, graduates ideally should be capable of a broad interdisciplinary vision [QS Intelligence Unit, 2017]. An interdisciplinary approach implies the ability to understand and solve problems by going beyond the concepts, techniques, and epistemological characteristics of specific disciplines, and merging them together [*Seow et al.,* 2019]. This requires being open to new ideas, curious, flexible, and inventive when applying experience gained in other professional domains to one's own [*Tait, Lyall,* 2007]. Such skills allow one to disregard conventional views and approaches in order to see one's objectives more broadly and comprehensively. As [*Oliver, Jorre,* 2018] demonstrated, if in 2011 none of the surveyed universities included interdisciplinarity into the expected results of education, in 2015, 22% of the universities did so.

Subject-specific knowledge remains extremely relevant for the technology and innovation sphere [*Collet et al.,* 2014]. Success in these areas depends not so much on creatively designing new solutions and applying them in practice, as on the ability to sell them in competition with people suggesting other approaches. Thus, future technology and innovation professionals must have all of the above six types of the 21st century skills, plus subject-specific knowledge. This mix will help one successfully apply the assets acquired over the course of education to subsequent professional activities.

Methodology of the Study

A key factor of human capital development is formal education at specialized educational organizations. One of the objectives of our study was evaluating formal education in Bachelor's and Master's programs. Baccalaureate is believed to make up the core of the education system providing a "broad" education, i.e. giving students a massive amount of basic knowledge and laying a foundation, including methodologically, for subsequent lifelong (self)learning [*Volkov et al.,* 2008]. A two-tier higher education system allows Bachelor's graduates to enter the labor market earlier, find out which specific knowledge and skills they need, and choose an appropriate Master's program. Furthermore, students can intentionally choose Bachelor's and Master's programs in different areas, combining various specialized skills and subject-specific knowledge [*Jacobs, van der Ploeg,* 2006]. Our *first hypothesis* is that the main value of a Bachelor's degree for graduates may be in creating a broad theoretical and practical base, while Master's programs provide the missing professional competences in specific areas.

Unlike the Baccalaureate, Master's programs are more specialized, designed to provide specific knowledge which (because it becomes obsolete relatively rapidly) remains outside the scope of the longer Bachelor's studies [*Volkov et al.,* 2008]. Bachelor's courses have a more general nature, while Master's programs are focused exclusively on the applied aspects of relevant disciplines [*Alessi et al.,* 2007]. The Baccalaureate can be seen as an entry point into a profession, while Master's programs and subsequent education stages can be seen as ways to acquire more precise and relevant professional skills [*Collins, Hewer,* 2014]. Our *second hypothesis* states that Master's programs train graduates to match the current changes in professional requirements, regardless of the chosen career path.

Lifelong (re)training is becoming increasingly important. According to our *third hypothesis* which takes into account the current education trends and related technologies, online courses became the most popular tool for upgrading qualifications [*Hamori,* 2018]. Acquiring relevant skills and qualifications requires constant personalized learning, which conventional upgrading programs provide only up to a point [*Egloffstein, Ifenthaler,* 2017]. And if at the early stage mass open online courses

(MOOCs) were mostly applied in the higher education context, lately the focus has shifted towards the corporate sector [*Dodson et al.,* 2015].

As MOOCs became more advanced, company personnel obtained the opportunity to develop their professional competences on their own, and at minimal costs (in effect for free), leading to increased productivity and improved general qualifications, optimizing certain work operations and becoming leaders in new areas [*Karnouskos,* 2017]. MOOCs allow one not only to find relevant materials and scale one's learning, but avoid taking on any additional obligations. This flexible personification of training depending on the trainees' needs makes MOOCs an extremely attractive tool for upgrading one's qualifications [*Park et al.,* 2015].

As [*Egloffstein, Ifenthaler,* 2017] demonstrated, MOOC students working for companies operating in various sectors of the economy see their professional development as the key objective. In other words, work- or career-related goals prevail over personal interests, though the respondents do not expect to be rewarded by their employer. On their part, companies also use this staff training and upgrading format increasingly often [*Karnouskos,* 2017]. MOOCs can help advance specific skills, or serve as prerequisites for subsequent in-depth corporate training which allows one to cut relevant costs [*Dodson et al.,* 2015]. Corporate online courses (only available to the organization's personnel) are also being designed and offered [*Egloffstein, Ifenthaler,* 2017].

The OECD experts identified six groups of most sought-after professional skills relevant for the innovation sphere: digital literacy, research abilities, subject-specific knowledge in relevant areas, general competences (e.g. critical thinking), soft skills (communication, teamwork), and leadership [OECD, 2011]. Skills most frequently mentioned in the literature include communication, interaction, and establishing social relations [*Lexen, Bejerholm,* 2016]. A recent study revealed that emotional intelligence of project team members has turned into an extremely important innovation activity factor [*Tsakalerou,* 2016]. According to our *fourth hypothesis*, science, technology, and innovation managers – the Master's program graduates – over the course of the last three years have found behavioral traits such as social and emotional intelligence to be particularly important [*Gutstein, Sviokla,* 2018].

We have conducted a survey of the English-language Master's program for managers of the science, technology and innovation (STI) sphere. The program is designed to teach skills such as analyzing innovation systems, designing and evaluating STI policies, and conducting foresight studies. Russian and international researchers with practical experience in international interdisciplinary studies, members of federal executive authorities, and businessmen (including start-up owners) are involved in teaching. During the training students have a chance to study at foreign partner universities, for short (in the framework of a student exchanges) or long (in the scope of dual diploma programs) periods. Since the program's launch in 2014, 104 students have graduated, of them 29 foreigners.

We adapted the Global Human Capital Index methodology [WEF, 2017] to measure human capital at the individual level. For each of the four sub-indices (capacity, deployment, development, and know-how) questions were designed to identify the relevant human capital elements (Figure 1). For example, to assess capacity, the respondents were asked to estimate the value of their education for their professional and career development. In terms of deployment, questions about the importance of education for career growth and adapting to changes at work were specifically formulated to match the Master's level. To measure the development sub-index, we asked questions about qualification upgrading mechanisms. The final element, specialized knowledge and competences (know-how) was assessed using a 10-point scale for each of the seven skill groups, followed by questions designed to explain the assigned scores and find out if there was any need to expand the list. Most of the questions were open and required an extended response, additional explanations were obtained during personal interviews with the respondents.

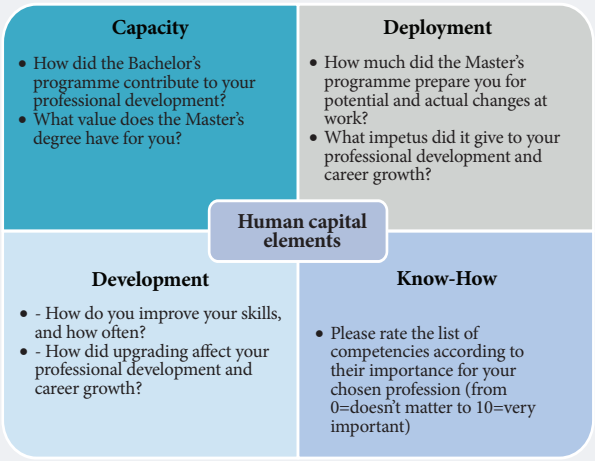
The survey was conducted using a qualitative method of semi-structured interviews. This allowed us to find out the respondents' individual opinions, perceptions, and career results taking into account the effect of specific factors in specific organizations and professions [*Hirschi et al.,* 2018]. A total of 16 Master's program graduates were interviewed, who have completed their studies in 2016-2018. The respondents were selected using a criteria-based approach [*Steinberg,* 2009] comprising two key indicators: graduation year and career path. The resulting sample (see Table 1 for the respondents' main characteristics) reflecting various career paths appears to be optimal for this kind of study. It allows one to take into account the variability of selected cases, while keeping the amount of repetitive information at a minimum [*Kvale,* 2008].

Most of the surveyed graduates represented two key career paths: the corporate sector (respondents 2-9, track CS), and R&D centers (respondents 12-16, track R&D), eight and five, respectively. Two more graduates have chosen to create their own companies (respondents 10-11, track S), and a single one opted for a career in public administration (respondent 1, track PA). Four out of the 16 respondents are foreign nationals.

Results of the Study

The first group of questions (the assessment of human capital) were related to estimating the value of

Figure 1. **Methodology**



Source: composed by the authors.

the formal education the respondents received. All of them gave it high marks, noting its role in accomplishing their personal and professional goals. Note that the respondents' perception of Bachelor's and Master's level education was quite different. Assessing their Baccalaureate, most of the respondents (11 out of 16) stressed the importance of theoretical and practical knowledge and skills that helped with their subsequent professional development (Figure 2): *"The university gave me a basic understanding of how markets work. This provided the core for accumulating further knowledge at work" (respondent 4, track CS)*. Five respondents stated that Bachelor's program not only helped them build the necessary theoretical foundation, but also promoted their personal development to become people who, as one of the graduates put it, *"always try to acquire new knowledge and experience" (respondent 3, track CS)*. Other important values included networking, extending social contacts, and developing soft skills (four mentions each).

The Master's degree was assessed as equally useful for further personal and career development (Figure 3). According to 11 respondents, it helped them acquire additional in-depth knowledge and specific competences they lacked after completing their Bachelor studies. One of the respondents noted that *"A distinctive feature of the Master's program was intensive training: the results achieved in two years' time were higher than those of the four year-long undergraduate studies" (respondent 2, track CS)*. However, this opinion seems to be an exception: in many cases the respondents assessed the value of Bachelor's and Master's education more or less equally, while describing them in totally different terms.

In terms of professional development and adapting to changes at the workplace (the second hypothesis), graduates received specific knowledge in areas such as STI governance, assessing its productivity, innovation economy mechanisms, strategic planning, and Foresight. This helped them integrate their previous experience gained in various areas and significantly expand the potential scope for professional activities.

Table 1. **The Sample of Respondents**

Respondent	Graduation year	Nationality	Type of organization	Industry	Career path (track)
1	2018	Russia	National	Public Administration and Military Security; Social Security	Public administration (PA)
2	2018	Russia	International	Management Consulting	Corporate sector (CS)
3	2018	Russia	International	Computer Software Development and Related Services	
4	2018	Russia	International	Information Technology	
5	2018	Russia	International	Information Technology	
6	2017	Russia	International	Management Consulting	
7	2017	Russia	International	Management Consulting	
8	2016	UK	International	Finance and Insurance	
9	2016	Russia	International	Telecommunications	
10	2018	Brazil	National	Information Technology	Start-ups (S)
11	2017	Russia	National	Administrative and Related Services	
12	2016	Turkey	International	Education	R&D
13	2016	Russia	International	Education	
14	2016	Russia	International	Education	
15	2017	Russia	International	Activities of Extraterritorial Organizations and Bodies	
16	2017	Romania	International	Education	

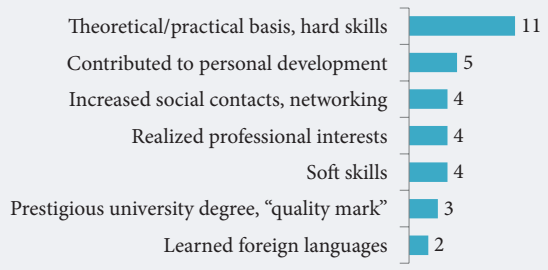
Source: composed by the authors.

On the whole, the graduates' positions turned out to be similar, summed up by the following quote: "*…after the two years in the Master's program, aspects beyond the daily workload became much more clear, which previously appeared to be blurred by distance*" *(respondent 7, track CS)*. Some of the graduates stressed the importance of research skills they acquired: "*The Master's program provides an understanding of how research should be structured, which techniques and data sources should be used in specific cases. In the light of this understanding, analytical materials are perceived differently: you can assess the quality of the authors' logic… Working on my Master's thesis helped me forge the ability to produce and structure analytical papers for the ministry's officials*" *(respondent 1, track PA)*.

For half of the respondents, the program opened new opportunities, new career and academic prospects. According to one of them, "*the courses I took first of all helped me find my way at the new job, and secondly, served as a good foundation for further development in the chosen area, including post-graduate studies*" *(respondent 15, track R&D)*. The graduates were able to focus on a specific professional area, and learn its specific features. Furthermore, both respondents representing the entrepreneurial track noted the program's role in their decision to start their own business: "*It was very important for me to get a broad understanding of Foresight techniques, strategic business planning, market studies tools, which resources were required to enter the market, investing, and minimizing risks*" *(respondent 10, track S)*.

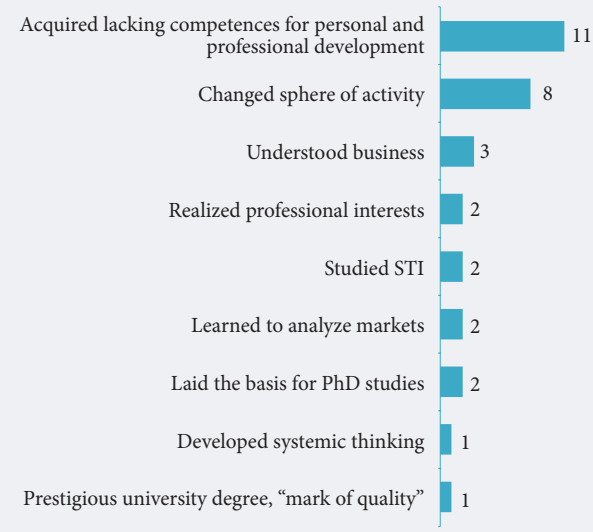
The third human capital element, development, allows one assess the mechanisms for increasing it through professional upgrading. Online education courses were the most popular format (applied by 15 of the 16 respondents), first of all in areas such as analytics, statistics, business models, and design. Training got the second largest number of mentions (10), with emotional intelligence development playing a particularly important role (mentioned by four respondents). Other ways to upgrade one's qualifications mentioned by the respondents included corporate training programs, further professional education courses, and PhD programs (Table 2).

Figure 2. **Bachelor Degree Value (number of mentions)**



Source: composed by the authors.

Figure 3. **Master degree value (number of mentions)**



Source: composed by the authors.

Regardless of the career path,[1] the respondents (four answers) did have opportunities to increase their human capital by taking part in relevant short-term training events including business training (three mentions). Graduates working for consulting firms used these opportunities most frequently: "*The company holds in-house training events all the time, in various areas*" *(respondent 7, track CS)*.

Apart from organized professional upgrading formats which can be seen as formal education, the graduates were engaged in informal educational activities including self-learning (Table 3). The main one was reading literature, first of all business and academic publications (three mentions each). The surveyed also mentioned taking part in professional events such as conferences, workshops, business case study analysis competitions, and so on.

The fourth group of questions were intended to assess the role of specialized skills and their application at work. The importance of seven key professional competences was rated using a 10-point scale. The average scores are presented in Figure 4.

All of the above skills were sufficiently important to the respondents. Still, they put social intelligence ahead of all others (giving it 8.9 points out of 10). In a situation of increasingly rapid robotization leading to job cuts [MGI, 2017], the graduates believed that having unique knowledge and practical skills became a key asset in defining people's competitiveness. The ability to establish partnerships and effi-

[1] Except startup owners.

Table 2. **Professional upgrading mechanisms**

Type	Name/subgroup	Number of mentions
Online courses (14 mentions)	Analytics and statistics courses (Big Data, DataCamp, Python)	6
	Business model and strategic design courses (product monetisation, strategic design, Skillbox UX analytics)	3
	Websites and applications to extend one's horizon	3
	Other training courses	2
Trainings (10 mentions)	Training courses to advance emotional intelligence	4
	Leadership trainings (SEO, Outbound Sales, Greenhouse program to advance leadership qualities and learn new approaches and techniques for analysts and consultants)	3
	Management trainings (IT Project Management, Information Security Management)	3
Short-term training events (4 mentions)	Business trainings (Accenture, EY, Yandex)	3
	Educational and social events at ministries	1
Continuing professional education (3 mentions)	Upgrading courses (at HSE University, project management at government agencies, business analytics)	3
PhD programs (2 mentions)	PhD programs from the leading universities in the United Kingdom and Belgium	2

Source: composed by the authors.

ciently negotiate also plays a key role in professional development.

It was suggested that the social intelligence concept itself was changing: *"Social intelligence used to be measured by the number of contacts in one's address book but then social networks arrived, along with thousands of contacts" (respondent 6, track CS).* In a professional community, communicating, and working under stress while multitasking requires developed emotional intelligence, which the respondents judged to be the second most important skill in this group (7.7 points out of 10). Many noted the importance of controlling one's own emotions. The third most sought-after competence turned out to be digital skills (7.5 out of 10). Several graduates also noted data analysis competences: *"You must be able to analyze and visualize any kind of data. Programming skills help with that. Such abilities allow one to extract valuable knowledge out of unconnected fragments" (respondent 13, track R&D)*. The importance of such skills was probably due to the fact that as the volume of available data grows, companies began using quantitative data to support decision-making more often [EIU, 2013].

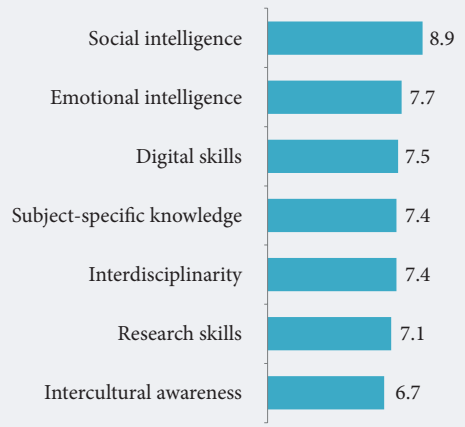
Subject-specific knowledge and interdisciplinary interaction skills were given identical scores (7.4 out of 10). This matches the T-shaped professional concept suggested by [*Guest,* 1991], which is based on the idea of developing a comprehensive personality combining deep knowledge with broad competencies. According to this logic, each worker has "two axes": horizontal (general competences) and vertical (special knowledge) ones.

The above concept becomes more relevant due to the need to handle the ever-increasing data flows. This was illustrated by one of the respondents: *"You cannot possibly have specific knowledge about every kind of task you deal with, but that's where your basic portfolio of knowledge and methodological approaches comes in to help" (respondent 1, track PA).*

The Master's program graduates received knowledge that helps them approach any analytical or prognostic task in a more systemic way. They assessed their training as multidisciplinary. At the same time the program allowed them to build individual career paths in terms of advancing specific knowledge and learning best STI practices and approaches alike.

The training also helped acquire research skills, whose importance the graduates assessed at 7.1 points. These include ability to think critically and identify core aspects in large data arrays. Only a few of the surveyed believed intercultural aware-

Figure 4. **Importance of key science, technology, and innovation skills (points out of 10)**



Source: composed by the authors.

Table 3. **Informal upgrading practices (self-learning)**

Type	Name/subgroup	Number of mentions
Reading literature (9 mentions)	Business literature	3
	Academic literature	3
	Books recommended by leading consultants (Big-3 and Big-4)*	1
	News media	1
	Industry-specific analytics	1
Conferences, exhibitions, business case studies, workshops (5 mentions)	Total *Out of that:*	5
	HSE events	1
	Events for entrepreneurs hosted by the Moscow City Business Development Department	1

* Note that the graduates recommended the following books: A. Auzan "Economics of Everything" [*Auzan,* 2014]; A. Osterwalder "Value Proposition Design" [*Osterwalder et al.,* 2014], D. Kahneman "Thinking, Fast and Slow" [*Kahneman*, 2011], D. Eagleman "Incognito: The Secret Lives of the Brain" [*Eagleman*, 2011], B. Dawn-Michelle "Kind Regards" [*Dawn-Michelle,* 2007], M. Gladwell "The Tipping Point: How Little Things Can Make a Big Difference" [*Gladwell,* 2000].

Source: composed by the authors.

ness skills were critically important, so their average score was the lowest, at just 6.7 points. Looking at the scores graduates assigned to various competences over the years, one can see that the importance of subject-specific knowledge was declining while that of emotional intelligence was growing (Table 4). This trend reflects the increasingly popular belief that lack of knowledge about a specific subject can be replenished quite rapidly these days while the development of soft skills, emotional intelligence in particular, takes much longer [*Haase, Lautenschlager,* 2011].

One of the respondents shared their personal experience of replenishing insufficient subject-specific knowledge while broadening their professional interests: *"You can accumulate knowledge rather quickly these days… and feel at home in a new area literally in a month or two" (respondent 9, track CS)*. However, this result should be treated with caution since the respondents' distribution by career paths was not proportional: the graduates working at R&D centers completed their studies in the program in 2016-2017, while half of the respondents representing the corporate sector graduated in 2018.

As to the factors that determine professional success, the corporate sector representatives valued the ability *"to take an objective and see it through"* particularly highly (respondent 9, track CS). Accordingly, they were interested not so much in having subject-specific knowledge as such, as acquiring the skills needed to apply this knowledge in practice. These workers were willing to learn basic theories, and over the course of their Master's education would like to get insights about their application in practical projects. In other words, they wanted to absorb information while conducting business case studies, modeling, and experimenting.

In its turn, working at R&D centers implies ongoing self-advancement in a specific domain, the ability to communicate with various people and learn useful competences from them: *"A specific feature of this work is the need to move on all the time. If you stop even for moment you immediately begin to lag behind" (respondent 13, track R&D)*. For graduates who chose this track, research competences were particularly important. However, they urged future students not to forget about applied aspects either, including best business practices.

For people running their own business, teamwork skills had key importance (coordinating, negotiating) as well as and priority-setting abilities.

Both representatives of this career path noted that finding new ideas and promoting creativity were turning into core competences in this field: *"It's not at all easy to put aside the ideas society imposes on you. But it's the only way to succeed, and achieve inner satisfaction" (respondent 11, track S)*.

The sole representative of the public sector assigned the highest importance to subject-specific knowledge and advanced social intelligence as the basis for shaping and implementing evidence-based government policy: *"Civil servants must have knowledge of financial, economic, and legislation-related issues, apply management skills in their daily activities, correctly communicate and establish contacts with professionals of various ages and persuasion" (respondent 1, track PA)*. They recommended that in the course of their studies, future Master's students should pay more attention to the program's management component and improve their knowledge of management.

Table 4. **Assessment of key STI-related skills' importance by graduation year**

Skills	2016	2017	2018
Research skills	7.8	6.6	6.8
Interdisciplinarity	7.6	7.2	7.5
Intercultural awareness	6.2	7.4	6.5
Subject-specific knowledge	8.2	8.0	6.2
Social intelligence	8.2	9.4	9.0
Digital skills	7.4	9	6.3
Emotional intelligence	6.0	7.6	9.2

Source: composed by the authors.

Conclusions

The labor market is being rapidly transformed by digitalization, which makes it necessary for workers to constantly advance their skills and acquire new competences. The goal of this study was to determine the role of human capital in professional development, using graduates of a relevant Master's program designed to train STI professionals as an example. We conducted in-depth interviews with 16 respondents representing various activity areas (public administration, the corporate sector, start-ups, and research institutes).

The study results confirmed most of the suggested hypotheses. Graduates value their higher education very much, though they assess participation in Bachelor's and Master's programs differently. The main advantages provided by the first of the aforementioned formats included a strong theoretical and practical basis, a broader scope for professional and personal development, networking, and the development of soft skills. As to the main benefits of Master's programs, the respondents mentioned additional competences and increased career potential.

In terms of practical application, the acquired knowledge helped the respondents to correctly conduct research using Foresight methodology and analyze and predict changes on the market. The Master's program helped them acquire teamwork skills, intercultural awareness, stress resistance, self-organization, and critical thinking abilities. Upgrading qualifications also plays a huge role in human capital development. The most popular form of achieving this was taking online educational courses.

Individual self-education practices were also identified, such as reading literature, participating in conferences, exhibitions, and workshops. Behavioral skills such as social and emotional intelligence and digital competences were particularly important for the STI sphere.

On the whole, regardless of their career path, the graduates noted the importance of the dynamic learning environment the Master's program created. Teamwork skills were naturally fostered while implementing joint projects. It also contributed to advancing interdisciplinary cooperation skills and making better decisions by pooling all team members' knowledge.

In terms of specific career paths, general management and project management studies were particularly important for graduates planning to work in public administration. Those oriented towards the corporate sector would welcome more active involvement of business experts and practitioners as teachers. This group displayed a growing interest in applying the knowledge they receive in practice. This demand can be met by providing information about various case study competitions and supporting students' participation in such events. For graduates interested in an academic career, tools to involve them in research activities of the faculty or division implementing the program should be developed. Representatives of various career paths noted the need to learn information handling skills during their participation in the program, such as processing and analyzing large volumes of unstructured data.

A limitation of this study was that the sample comprised only graduates of the single Master's program. Benchmarking or analyzing the best international STI-relevant teaching practices could produce more detailed results. The effect of the graduates' previous education (participation in Bachelor's programs) on their subsequent professional development remained outside the scope of the study.

Keeping in mind the intercultural nature of the program, specific features of Russian and international students should be identified. The sample used in the current study was small and not balanced in terms of representing various career paths. For example, public administration was represented by a single respondent. Extending the sample and making sure the graduates are more evenly distributed between career tracks would allow one to obtain deeper insights regarding the required skills and factors affecting successful development in the context of specific career paths.

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