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Adapting education to industry 4.0: a comparative study

Adaptando la educación a la industria 4.0: un estudio comparativo

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Abstract

Objective: this study conducts a comparison among three countries (i.e., Colombia, Germany, and South Korea) on the adaptation process of their educational systems within the framework of Industry 4.0. **Method:** a comparative study of multiple cases to analyze the differences between these countries, which are considered as ideal types of events in central and peripheral countries to understand the differences and similarities among their educational strategies. Analysis is based on secondary sources of information that enable comparability among the three countries. In addition, a documentary analysis intends to shed light on the educational systems and strategies proposed for each country. **Results:** evidence is obtained of various educational policies implemented in the three countries, which leads to doubts about the capacity of peripheral regions to remain up to date in this area. **Discussion and Conclusions:** many aspects, such as the level of economic development and central or peripheral position, directly influence the type of strategy applied by each country and its success rate.

Keywords: industry 4.0, education, comparative study.

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Resumen

Objetivo: desarrollar un estudio comparativo entre tres países (Colombia, Alemania y Corea del Sur) sobre el proceso de adaptación de sus sistemas educativos en el marco de la Industria 4.0. **Método:** estudio comparativo de casos múltiples para analizar las diferencias entre estos países considerados como tipos ideales de lo que ocurre en los países centrales y periféricos para entender cuáles son las diferencias y similitudes entre sus estrategias educativas. El análisis se basa en fuentes secundarias de información que permiten la comparabilidad entre los tres países, así como en un análisis documental destinado a comprender el sistema educativo y las estrategias propuestas en cada país. **Resultados:** se evidencia variedad en políticas educativas entre los países, planteado dudas acerca de la capacidad de las regiones periféricas para estar el día en esta temática. **Discusión y Conclusiones:** aspectos como el nivel de desarrollo económico y la posición central o periférica influyen directamente en el tipo de estrategia aplicada por cada país y en el éxito alcanzado por el mismo.

Palabras clave: industria 4.0, educación, estudio comparativo.

Introduction

The possibility that countries must adapt and contribute to changes due to Industry 4.0 is diverse and differ according to the levels of economic, social, and technological development. Many studies demonstrate that peripheral countries of the Global South face serious difficulties in scaling up in the context of increased spatial division of labor and fragmentation of production in global value chains. This scenario is due to deficiencies in infrastructure and installed capacities, among other factors, that hinder the catch-up (Speringer y Schnelzer, 2019; Brixner et al., 2020; Primi y Toselli, 2020). One of the dominant themes of works that examined this topic is the effect of Industry 4.0 on work and, especially, on the risk posed by the changes it produces to the increased destruction of jobs (Lasi et al., 2014; Roblek et al., 2016; Erro and Arañaz, 2020). In this context, education becomes a key factor in facing the challenges posed by Industry 4.0 (Cardoso et al., 2017; Abbas et al., 2019; Zhang et al., 2019).

The objective of this article is to compare how the educational systems in Colombia, South Korea, and Germany are adapting to the challenges of Industry 4.0 to understand the extent to which these systems address the different gaps that exist for each country. Moreover, the study considers their differences in terms of the levels of economic and technological development and intends to understand the extent to which the need of different types of education policies can contribute to the reduction of the gap between core and peripheral countries. This analysis aims to fill the existing research gap on comparative studies in the field of studies on Industry 4.0 in general and in aspects related to education strategies, which are considered key for the leapfrogging of developing economies in particular.

This research proposes a multiple-case comparative study design to analyze the differences among Colombia, South Korea, and Germany. The characteristics of these countries could enable us to identify differences and similarities between core (Germany and South Korea) and peripheral countries (Colombia) in the strategies adapted by their educational systems to the challenges of Industry 4.0. These countries represent three ideal types in terms of incorporating Industry 4.0. Germany and South Korea are core countries although with different characteristics. Germany is the creator of the concept of Industry 4.0 and a world leader. South Korea also occupies a core position but represents a country that was able to *scale up* to leadership positions in the global economy over the previous four decades (Kyung, 2018; Erro and Arañaz, 2020). In contrast, Colombia is a typical case of a peripheral country in the international context. It has reached a medium level of development but continues to face problems to achieve universal education and the development of its digital economy (Organisation for Economic Co-operation and Development [OECD], 2019a). Analysis is based on secondary sources of information that enable comparability among the three countries followed by a documentary analysis that intends to elucidate the education curricula and policies of each country. The results demonstrate significant differences in educational strategies oriented toward Industry 4.0. Although Germany and South Korea exhibit higher levels of convergence, Colombia is continuing to resolve historical deficiencies and training deficits, which could question its ability to take advantage of the opportunities offered by Industry 4.0. In this sense, this convergence is likely to happen in Colombia only in certain niche markets and organizations that function as islands of efficiency.

The article is divided into four section. The first analyzes the different strategies for adapting to Industry 4.0 that can be observed between the most developed countries and those located on the periphery and pays special attention to educational strategies. The study methodology is then discussed. The third section presents the results given three dimensions of comparison, namely, coverage of the educational system, characteristics of the curricula, and integration into the labor market. Finally, the conclusions of the work are presented.

How industry 4.0 challenges education across contexts

This section consists of three parts. The first part introduces the concept of Industry 4.0; the second part analyzes the different strategies employed by different countries to adapt to Industry 4.0; finally, the educational challenges of Industry 4.0 are presented.

Introduction to Industry 4.0.

Disruptive processes, which are mainly technological changes applied to the industry in the modern era, are known as industrial revolutions (Encyclopædia Britannica, 2019; Corona et al., 2020). Thus far, four main revolutions are identified (Roser, 2016), namely, first: mechanization, waterpower, and steam power; second: mass production and assembly line; third: computer and automation; and fourth: cyber-physical systems, which are also known as Industry 4.0.

According to Sreedharan and Unnikrishnan (2017), the concept of Industry 4.0 was initially presented at the Hannover Fair in 2011 as a project strategy of the German industry and was later adopted by the World Economic Forum. The authors found that the typical definitions of Industry 4.0 refer to a combination of cyber-physical systems[1] linked to supply chains and manufacturing processes using the Internet of Things and industrial development. Changes linked to the emergence of Industry 4.0 are also known as *Integrated Industry*, *Industrial Internet*, S*mart Factories*, Sma*rt Industry*, and *Advanced Manufacturing*, among others. Moreover, various definitions were proposed, where a few authors even questioned whether or not it is a new technological paradigm or an extension of the third industrial revolution (Brixner et al., 2020). Table 1 presents this diversity.

One of the reasons for this lack of consensus is due to the fact that the transformation of the manufacturing industry exceeds the factory and integrates logistical elements and value creation models that influence the evolution of the sector, among others. Therefore, other sources, such as i-SCOOP,[2] Forbes,[3] and Hannover Messe, [4] began coining the term "Logistics 4.0" for the transformation of entire supply chain. Today, Industry 4.0 is moving toward smart transportation and logistics, smart buildings, smart healthcare, or smart "anything." However, this expansion is inhomogeneous across countries. The global fragmentation of production since the 1990s has led to the emergence of a new spatial division of labor characterized by a functional specialization whose results remain difficult to predict in terms of convergence or divergence (Baldwin, 2019; Timmer et al., 2019; Brixner et al., 2020).

Table 1.
Definitions of *Industry 4.0*

Source	Definition
BDI (2019)	An increasing number of machines are connected to the Internet. After mechanization (Industry 1.0), mass production (Industry 2.0) and automation (Industry 3.0), the "Internet of Things and services" is currently becoming an integral part of manufacturing. Industry 4.0 paves the way for personalized products, efficient logistics, new services, and flexible working environments.
Germany Trade and Invest (2014)	The smart industry or "INDUSTRIE 4.0" refers to the technological evolution from embedded systems to cyber-physical systems. Simply put, INDUSTRIE 4.0 represents the coming Fourth Industrial Revolution on the way to an Internet of Things, Data, and Services. INDUSTRIE 4.0 represents a paradigm shift from "centralized" to "decentralized" production-made possible by technological advances which constitute a reversal of conventional production process logic.
McKinsey (2015)	Industry 4.0 is the next phase in the digitization of the manufacturing sector, which is driven by four disruptions, namely, astonishing increases in data volume, computational power, and connectivity, especially new low-power wide-area networks; the emergence of analytics and business-intelligence capabilities; new forms of human-machine interaction such as touch interfaces and augmented-reality systems; and improvements in transferring digital instructions to the physical world.
SAP (2015)	Industry 4.0 is a collective term for technologies and concepts of value chain organization. Based on the technological concepts of cyber-physical systems, the Internet of Things, and the Internet of Services, it facilitates the vision of the Smart Factory. Within the modular structured Smart Factories of Industry 4.0, cyber-physical systems monitor physical processes, create a virtual copy of the physical world, and make decentralized decisions.

[1] A *Cyber-Physical System* — CPS is "any device that integrates computing, storage and communication capabilities to control and interact with a physical process" (CantabriaTIC, 2015)

[2] https://www.i-scoop.eu/industry-4-0/#What_is_Industry_40_according_to_several_sources

[3]https://www.forbes.com/sites/insights-inteliot/2018/06/14/logistics-4-0-how-iot-is-transforming-the-supply-chain/#464d4cbd880f

European Parliament (2015)	Industry 4.0 is a term applied to a series of rapid transformations in the design, manufacture, operation, and service of manufacturing systems and products. The 4.0 designation signifies that this is the world's Fourth Industrial Revolution, the successor to the three earlier industrial revolutions that caused quantum leaps in productivity and changed the lives of people throughout the world.
Gartner (2015)	Industry 4.0 is a German-government-sponsored vision of advanced manufacturing. The underlying concept of Industry 4.0 is to connect embedded systems and smart production facilities to generate a digital convergence between industry, business and internal functions and processes. Industry 4.0 refers to a Fourth Industrial Revolution and introduces the concept of "cyber-physical systems" to differentiate this new evolutionary phase from the electronic automation that has gone before.

Source: i-SCOOP compilation. (i-SCOOP, s.f.)

Different paths of development in the adaptation to Industry 4.0

The incorporation and preparedness of countries for Industry 4.0 vary according to their level of economic development. The more developed countries propose strategies for maintaining their leadership position in the development of new technologies, whereas those from the Global South intend to develop this type of industry to achieve convergence through technological catch-up (Speringer y Schnelzer, 2019). In any case, development strategies related to Industry 4.0 differ among countries and exceed the simple distinction between the Global North and South from various aspects. Examples are orientation toward exports or the domestic market, government participation and private initiative, or degree of concern for solving future problems that will affect labor markets due to mechanization and robotization. As will be discussed, this scenario translates into the manner in which each country faces the development of its educational system.

The development of Industry 4.0 shapes and modifies the global organization of production with consequences for inequality among countries that remains difficult to foresee (Baldwin, 2019). The integration of countries into global value chains (GVCs) is directly related to their capabilities and opportunities for technological development and, therefore, with the participation of each country in the application of Industry 4.0 (World Bank, 2020). In this sense, the countries of the Global South, particularly Latin American countries, tend to be weakly integrated into GVCs mainly as suppliers of raw materials, basic products, and low value-added manufacturing (World Bank, 2020). They also have economies with low levels of complexity and are far from the three macro-regions, where the majority of the intra-industry trade is concentrated (Hidalgo and Hausmann, 2009; Hausmann and Hidalgo, 2010). In contrast, the countries of the Global North are strongly integrated into GVCs around three major global macro-regions, namely, Southeast Asia, Europe, and North America, as suppliers of innovative activities and high value-added manufacturing and services. They are also economies with higher levels of diversification and complexity.

In a context where the functional distribution of work (what is done) versus the sector (what is produced) is becoming increasingly important, inferring that the proposal of the development of Industry 4.0 is going to follow different paths for each country is logical (Timmer et al., 2019). The challenges faced by different national economies differ significantly to the extent that labor markets can be more affected by the processes of increased mechanization and robotization of production. This tendency occurs if tasks performed by countries are more on routine and less on creativity and differ in function from strategies that each country considers for integration into their economy in the GVCs. Nevertheless, obtaining a skilled workforce with the competencies required for the development of Industry 4.0 becomes imperative for the promotion of economic development. In this sense, countries differ in the manner that their educational systems address the adaptation to the development of Industry 4.0. Thus, analyzing the extent to which the strategies of the Global South resemble or not those followed by more developed countries is relevant. The reason is that having qualified workers for the challenges posed by this technological revolution is one of the necessary conditions for achieving increased integration into GVCs and, ultimately, to achieve high levels of economic development.

Adapting education to Industry 4.0.

The direct impact of Industry 4.0 in the world of work also directly links it with changes in educational models. However, countries will be unable to propose similar strategies. The challenges that educational systems face in their adaptation to Industry 4.0 differ according to the level of economic development of a country. Peripheral countries continue to face the need to guarantee universal access to education and, in the majority of cases, gain limited access to basic infrastructure such as the Internet (Brixner et al., 2020; Pineda, 2021). Furthermore, their functional specialization in routine tasks and services with low cognitive content puts pressure on their educational systems to train individuals in competencies that could be among those that can be easily replaced by robotization and other processes linked to the expansion of Industry 4.0, which could aggravate unemployment problems that have been persistent in the periphery (Primi and Toselli, 2020). In this sense, these countries face limitations in terms of installed capacities, infrastructure, and productive specialization, which could become insurmountable in relation to a true technological catch-up (Brixner et al., 2020; Primi y Toselli, 2020).

Educational policy options differ dependent on variables, such as the integration of countries into global chains, their functional specialization, installed capacities, and the starting point of educational systems. Therefore, viewing "one size fits all" policies as inappropriate is necessary, such that they must be adapted to different contexts according to priority. Countries seek the best options in training their human capital and obtaining competitive advantages in terms of the application and development of knowledge. However, specific curricula should be designed dependent on the decisions of the time and content of education offered to their population. This design reflects national or regional priorities of preferences in terms of skills and values that should be taught to students and at what age (OECD, 2019a).

As an organization dedicated to helping countries manage development in education, the United Nations Educational, Scientific and Cultural Organization (UNESCO) is aware of the challenges of different national contexts. In a report entitled, "Progress towards

Education for All," the results show a combination of success, failure, and decline, as well increased complexity for achieving the goals of "Education for All." UNESCO's vision as a relatively linear progress is now strongly impacted by various national, regional, and global events and circumstances (UNESCO, 2011; UNESCO, 2015). The OECD Centre for Educational Research and Innovation recognizes that certain contextual factors influence education policy, such as demographics and socio-economic and political factors. As an example, they mention the impact of an economic crisis on the availability of funds for education and the characteristics of the students in terms of gender, age, socio-economic situation, and cultural background, among others (OECD, 2018a).

For the comparative analysis, this study considers two determining elements of the design and results of educational policies. The first is the situation of Industry 4.0, which implies the analysis of factors such as productive specialization and access to infrastructure linked to connectivity. Second, the study examines the starting point of the educational system to analyze the extent to which universal access to education has been achieved and to elucidate the structure of student participation at different levels of education. Moreover, the study intends to determine the extent to which students are integrated into labor markets. These two elements will enable us to better elucidate the reasons that underlie the current curriculum structure in the three countries as well as the manner in which the educational system is linked to labor markets.

Method

This research proposes a comparative study design of multiple cases to analyze the differences among Colombia, South Korea, and Germany. The characteristics of the three countries enables the identification of differences and similarities between core and peripheral countries in terms of strategies employed to adapt their educational systems to the challenges of Industry 4.0. This approach also allows the replication of findings across cases or the prediction of contrasting results based on a particular case (Yin, 2013). In the same manner, the research follows the three principles established by Yin (2013, p. 101) for conducting high-quality case studies, namely, using multiple sources of evidence (quantitative and qualitative); creating a database for the case study, and maintaining a chain of evidence. Two analytical techniques will be used, namely, pattern matching, where an empirically based pattern is compared with several predicted ones (ideal types of core and peripheral countries) and cross-case synthesis, in which each case is treated as a separate study (Yin, 2013).

This research design could enable the determination of the major similarities and differences among the three countries in level of development, incorporation into Industry 4.0 and educational systems, and the influence of these differences on the prospects of successful integration into the global economy.

Comparative studies with international benchmarks are a key pillar in the development of government education policies. Countries intend to learn from others to ensure that their decisions deliver the expected results on key issues such as access to education, emerging competencies, and teaching/learning strategies for the life cycle of people (i.e., the number of compulsory years, starting age, levels, and contents of education). To support these decisions, standards, such as the International Standard Classification of Education (ISCED) are developed. Moreover, international entities, such as UNESCO, OECD, and the World Bank, conduct studies in addition to policy guidelines formulated by planning entities nationwide.

The proposed comparative analysis is based on three countries that represent three ideal types in terms of the incorporation of Industry 4.0. Germany and South Korea are core countries although with different characteristics. Germany is the creator of the Industry 4.0 concept and a world leader; South Korea occupies a core position but represents a country that was able to scale up to leadership positions in the global economy over the previous four decades (Kyung, 2018; Erro and Arañaz, 2020). In contrast, Colombia is a typical case of a peripheral country in the international context. It has reached a medium level of development, but it still has a strong dependence on the export of natural resources, and its efforts are mainly aimed at adapting, with different degrees of success, the best technologies that have helped the leading countries in the industrial revolution 4.0 (OECD, 2019a).

Analysis is based mainly on secondary sources of information that enable comparability among the three countries followed by a documentary analysis that intends to elucidate the education curricula and policies proposed in each country. To identify patterns of similarities and differences, the study considers three dimensions of analysis, namely, participation in the educational system, the curricular structure, and the integration of students into the labor market. From this analysis and as a synthesis of the comparison, the study analyzes education policies oriented toward Industry 4.0 in each country.

The following stages were conducted in the research: bibliographic search, problem statement, bibliographic analysis based on a systematic literature review, selection of categories of analysis and elaboration of the theoretical framework, and comparative analysis.

For documentary analysis, the study developed a systematic literature review matrix based on six criteria, namely, research question, inclusion criteria, databases, search terms, initial search results, and evaluation of results. The first search in the databases yielded a total of 137 articles and academic texts, from which 58 texts were selected on the basis of the criteria of the review matrix. Afterward, the theoretical framework was constructed; data for analysis were obtained; and the comparative study was performed.

Results

This section presents the results of the study based on a comparative analysis of the economic structure of each country and its degree of progress in Industry 4.0.

General characteristics and situation of Industry 4.0

The selected countries present varying degrees of development in their industries, structures, and specialization. As previously stated, Germany and South Korea can be considered ideal cases of core countries or leaders in the development of Industry 4.0, although with significant differences between them. Meanwhile, Colombia is an ideal type of country on the periphery of the Global South with its intermediate development and aspiration to take a technological leap to enable it to catch up.

In 2020, the differences in gross domestic product (GDP) per capita among the three countries were significant: Germany with $55,314 GDP per capita is clearly above South Korea at $43,044 and more than tripling that of Colombia at $14,257 GDP per capita (World Bank, 2019). The World Economic Forum (WEF; 2018) confirmed these differences in terms of the degree of complexity of the production structure and the existence of drivers of production in each country. Its assessment included indicators that capture concepts pertinent to the readiness of a country for the future of production (e.g., complexity, scale, technology and innovation, human capital, global trade and investment, institutional framework, sustainable resources, and demand environment). The report stated that Germany and South Korea are among the *leading countries*, whereas Colombia is in the category of *nascent countries* (Table 2). From another perspective, the United Nations Human Development Index (HDI) illustrated the leadership of Germany followed at a certain distance by South Korea. Especially notable in the HDI is the significant distance demonstrated by Colombia in the selected indicators related to schooling (Table 3).

Table 2.
Structure and drivers of production

Country	Structure of Production		Drivers of Production	
	Score*	Rank	Score*	Rank
Germany	8.68	3	7.56	6
South Korea	8.85	2	6.51	21
Colombia	4.61	56	4.53	65

Source: World Economic Forum (2018).

Table 3.
Human Development Index Ranking and Selected Indicators of Education

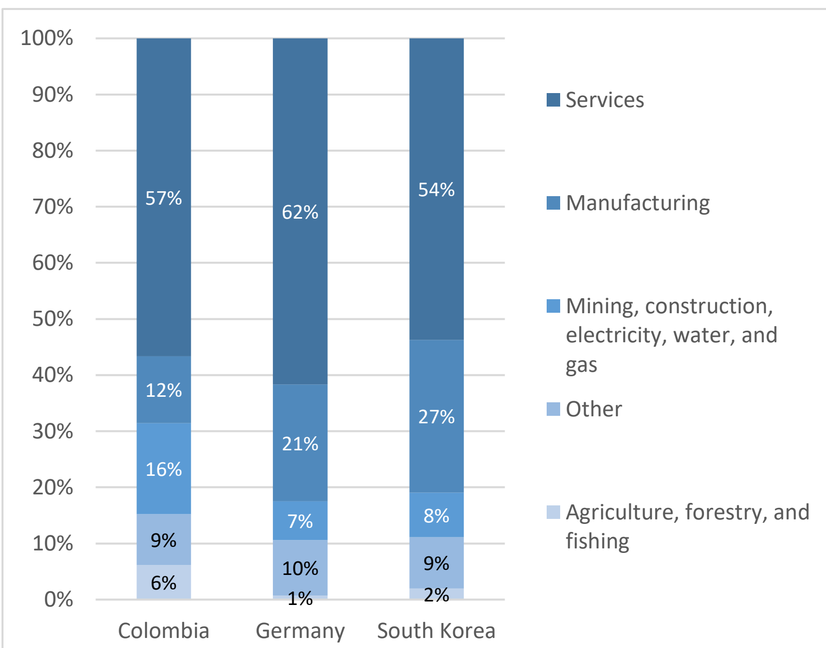
Country	Rank	Human Development Index	Expected years of schooling	Mean years of schooling
Germany	6	0.947	17.0	14.2
South Korea	23	0.916	16.5	12.2
Colombia	83	0.767	14.4	8.5

Source: United Nations Development Programme (2020)

Although the three countries are tertiary economies with a service sector above 50% of GDP, they present significant differences in terms of production structure. Notably, the greater participation of the manufacturing sector in Germany and especially in South Korea represents 21% and 27% of the GDP, respectively, whereas it is only 12% in Colombia

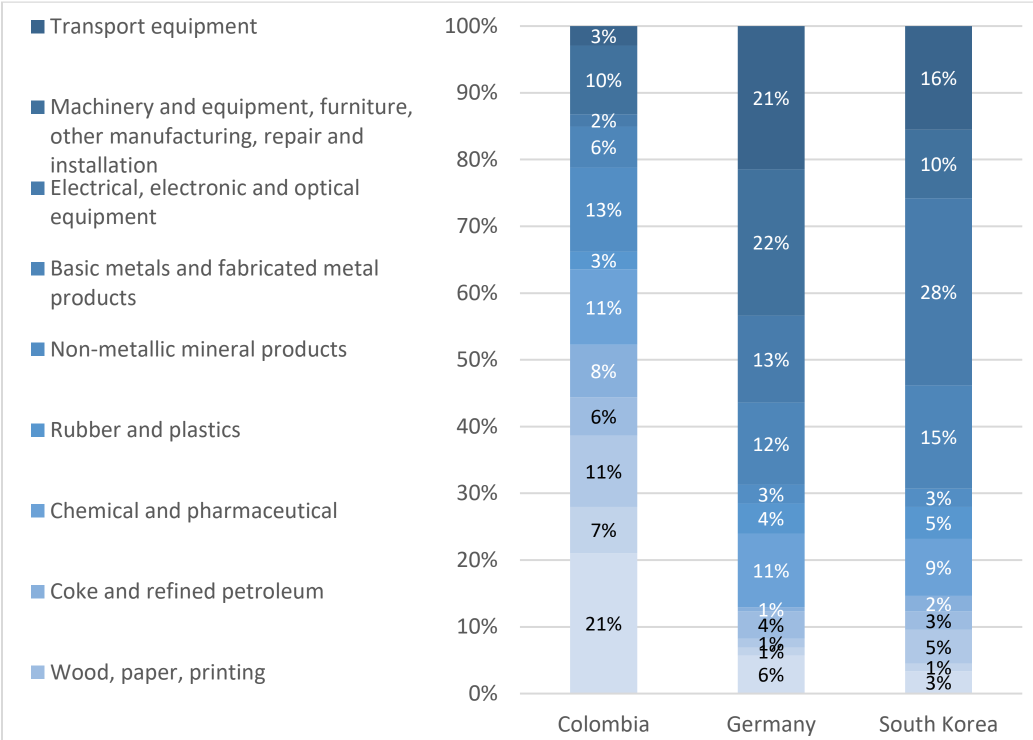
(Figure 1). In contrast, Colombia maintains a strong dependence on agricultural production, mining, electricity, gas, water, and construction, which represent more than 22% of GDP when combined. Colombia not only has less manufacturing activity but also raw material-intensive activities, such as food, textiles, wood, and refineries, which account for 52% of its industrial activity. On the contrary, Germany and South Korea have an industry oriented toward the production of machinery and equipment, appliances, vehicles and other related products, which represent approximately 70% of the manufacturing production for both countries (Figure 2). Furthermore, from the functional perspective, Germany and South Korea are characterized by increased specialization in research and development, management, and marketing functions, whereas Colombia tends to specialize in manufacturing functions, which have less complexity and cognitive content (Timmer et al., 2019). This evolution puts Germany in a position of coordination of GVCs; South Korea as a follower capable of achieving technological catch-up; and Colombia within the group of follower countries but with specialization in assembly tasks and transformation of raw materials (Primi y Toselli, 2020).

Figure 1.
Value added structure. % GDP (average 2014-2018)



Source: World Bank (2019), World Development Indicators

Figure 2.
Composition of the manufacturing industry



Source: OECD (2018b) and DANE (2018)

The previous results confirm the leadership position of Germany, the technological catch-up achieved by South Korea, and problems that Colombia faces to follow the path to adopt and take advantage of Industry 4.0. Colombia faces a transition that could move between two opposing paths. The first is a slow and gradual path that can leave the country behind and imprisoned in the middle-income trap. The second is to take a leap along the way, which is known as *leapfrogging*. The term is coined by Schumpeterian economists and seeks to take advantage of windows of opportunity presented by new technological paradigms for developing countries (WEF, 2018; Brixner et al., 2020; Primi and Toselli, 2020).

According to Dewa et al. (2018), expecting industries to immediately achieve an Industry 4.0 upgrade is unrealistic for a country. In this sense, Zhou et al. (2015) and Jones and Pimdee (2017) suggest industrial development models in which parallel advances in Industries 2.0 and 3.0 are presented to reach Industry 4.0. However, these models consider that many of the technological systems attributed to the new paradigm of Industry 4.0 were previously present in the past decades (Brixner et al., 2020). Consequently, a gradual approximation can be obtained by examining the legacy of previous revolutions. Developing countries face similar challenges in transitioning toward Industry 4.0, which includes including middle-income and inequality traps. As such, no formulas exist in making such a leap, although the attraction of foreign investment, investment in physical infrastructure to increase connectivity, and education stand out among the most mentioned actions (Brixner et al., 2020; Erro and Arañaz, 2020; Primi and Toselli, 2020).

Specifically, the human resource of a country needs to acquire the knowledge and capabilities necessary for adopting and creating new knowledge despite the difficulty in adopting new techno-economic paradigms.

Comparison of educational systems: similarities and differences

The study compares three dimensions of the educational systems of the selected countries, namely, degree of participation of the population in varying levels of the system, characteristics of the curricula, and degree of labor integration.

Participation in the educational system

The countries analyzed reveal important differences in student participation at varying educational levels (Table 4). Colombia exhibits a limited level of incorporation into higher education of the population aged between 25 and 64 years with a prevalent rate of students belonging to below upper secondary school. In contrast, South Korea displays the highest rate of enrollment of students at the tertiary level at nearly 50%. The case of Germany is especially interesting due to the low level of incorporation of students into university degrees at approximately 30%. This rate is partially attributable to the weight given by its educational system to upper secondary vocational training, where certain programs, such as nursing, allow people to legally work as basic-level professionals (World Education News + Reviews, 2016). When comparing the percentage of the population with tertiary education in the groups aged between 25 and 34 years and between 55 and 64 years, a large growth is observed in the three countries. This case is especially true for South Korea, which triples the participation of students reaching 70% in younger generations. Colombia doubles such participation to nearly 30%. Once again, Germany indicates a different educational model, which reaches 32% of participation in tertiary education for the population aged between 25 and 34 years despite its higher level of economic development. This percentage is only slightly higher than that of Colombia.

Although the years of compulsory education in Colombia are similar to those of Germany and higher than those of South Korea, Colombia presents problems in guaranteeing the participation of a significant portion of its school-aged population. Moreover, its difference with the two other countries in early childhood education is more pronounced: enrollment rates for ages four and five are approximately 60%, whereas the populations in Germany and South Korea within this age range practically enjoy universal access. In addition, differences are observed in the quality of education through the results of PISA tests for reading, mathematics, and science, where the gap of Colombia from South Korea and Germany is especially significant in the last two areas. In summary, Colombia is a country that continues to have a large part of its population with relatively low levels of education and that is moving toward increased participation in secondary and tertiary education. South Korea makes a nearly complete transition to universal basic education and displays a strong commitment to the expansion of tertiary education.

Lastly, Germany achieves universal basic education but mainly focuses more on the development of vocational secondary education and less on tertiary education.

In addition to these differences in the structure of participation in education, the university systems present marked contrasts in dominant areas of knowledge. In Colombia, students of engineering, manufacturing, natural sciences, information, and communication technologies (areas commonly associated with Industry 4.0) are significantly lower and less than half the proportions of Germany and South Korea. Another peculiarity is that Colombia indicates a higher concentration of graduates in education, which suggests that it retains a very academic orientation complemented by the structure of the curricula.

One of the aspects that is directly connected to the opportunity to achieve technological catch-up together with education is the connectivity infrastructure, which has become increasingly evident during the COVID-19 pandemic. Particularly in education, the lack of access to online education may be increasing the gaps between families. Differences in this regard are very pronounced. South Korea and Germany virtually achieve universal Internet access at home, whereas this figure remains at approximately 50% in Colombia. This gap is also true for students and teachers who are unfamiliar with available platforms and challenges of online education (Table 4).

Characteristics of the curricula

Education systems are ruled by a qualification framework that is dependent on national policies. The study observed structural and cultural differences among the countries, including compulsory years of study, starting age for education, the level at which a specific specialization route is introduced, and approaches to vocational or complementary education, among others. Similarities and differences in curricular structure can provide insights on how countries are adapting to the demands of Industry 4.0. To establish a framework that enables comparison between countries, the study employs the UNESCO International Standard Classification of Education (ISCED), which standardizes the structure of educational systems using a series of levels and associated characteristics. The focus is on upper secondary and higher education levels (UNESCO, 2019).

ISCED maps formulated by the OECD (2019b) illustrate significant differences between modalities and study options provided by the curricular structure for students, particularly in terms of vocational and part-time programs. Figure 3 compares the curricular structure of the three countries. After the lower secondary levels, the Colombian model is significantly simpler and presents a marked differentiation between basic and technique education, which has no direct connection to subsequent studies. Nevertheless, an individual could seek homologation for university studies (if the possibility exists in the institution) or take more time to complete their studies. In contrast, a greater complexity exists for South Korea and Germany in terms of options for students. The results highlight vocational-oriented programs that offer additional paths for students and lead them to high levels of specialization at high ISCED levels.

Table 4.
Indicators of education

Indicator		Colombia	Germany	South Korea
Adult education level, % of 25–64-year-olds (2018 or latest available)*	Below upper secondary	45%	13%	12%
	Upper secondary	32%	58%	39%
	Tertiary	23%	29%	49%
Adult education level, % of population on the same age range (2018)*	tertiary 25–34-year-olds	29%	32%	70%
	tertiary 55–64-year-olds	15%	26%	23%
Secondary graduation rate, % (2017)*		79%	81%	95%
Enrollment rate in secondary and tertiary education, % in the same age group (2017)*	17-year-olds	56%	93%	94%
	18-year-olds	43%	81%	71%
	19-year-olds	36%	68%	74%
Enrollment rate in early childhood education, % in the same age group (2017)*	3-year-olds	53%	91%	94%
	4-year-olds	62%	95%	97%
	5-year-olds	58%	97%	92%
Compulsory education, duration (years)**		12	13	9
Share of tertiary graduates by field of study (2017)*	Business, administration, and law	22%	23%	15%
	Arts and humanities, social sciences	10%	19%	22%
	Health and welfare	20%	7%	16%
	Education	33%	12%	7%
	Engineering, manufacturing, and construction	11%	22%	20%
	Natural sciences, mathematics, and statistics	1%	9%	5%
	Information and Communication Technology	1%	5%	5%
PISA (performance of 15-year-old students), mean score (2018)***	Reading	412	498	514
	Mathematics	401	503	528
	Science	420	502	521
Internet access Total, % of all households, 2018 ****		53%	94%	100%

Note: OECD (2019), Education at a Glance 2019: OECD Indicators, OECD Publishing, Paris, https://doi.org/10.1787/f8d7880d-en

**World Development Indicators

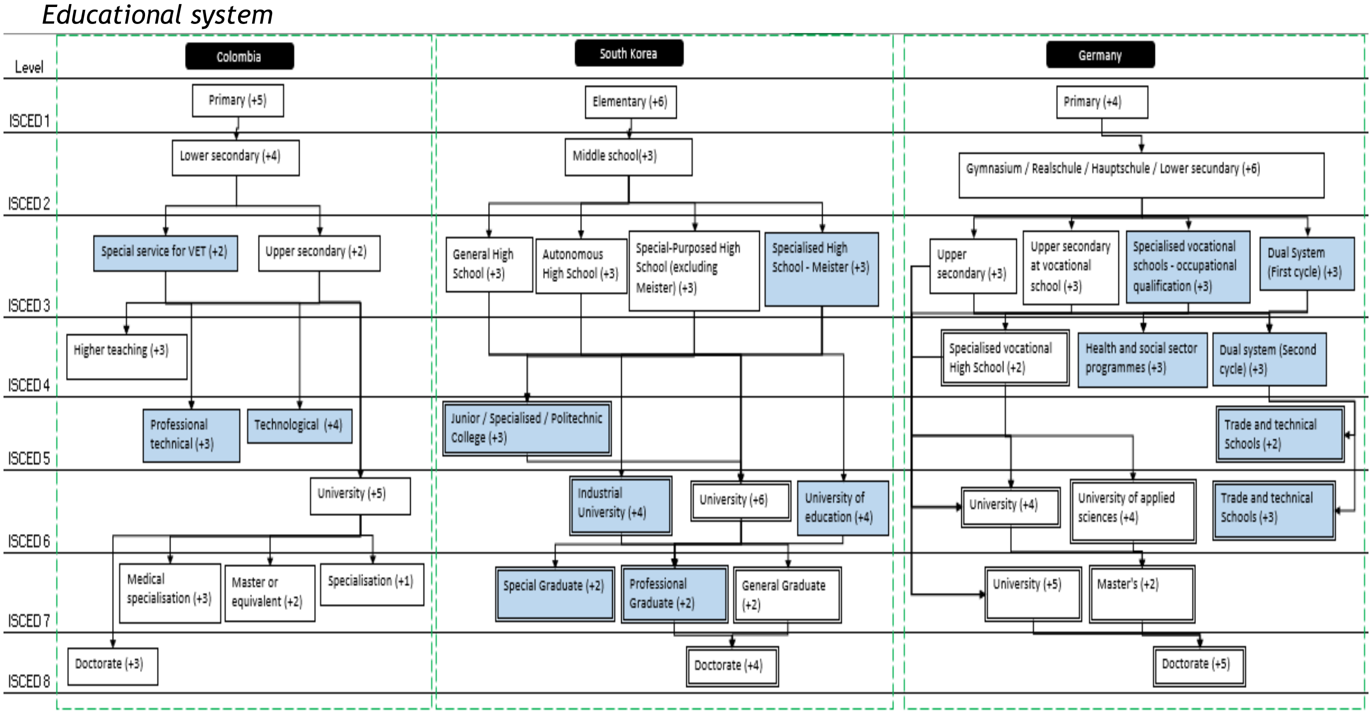
***OECD (2020), PISA 2018 Results, PISA, OECD Publishing, Paris, https://doi.org/10.1787/48ebd1ba-en.

**** OECD (2017), OECD Digital Economy Outlook 2017, OECD Publishing, Paris, https://doi.org/10.1787/9789264276284-en

Another characteristic of the curricula in Germany and South Korea is that they offer programs designed to be part-time given various aspects such as the combination of time for academic studies and apprenticeship leading to certification in a particular field of work. Particularly at ISCED levels 6 and 7, the study observes vocational and miscellaneous programs that lack clear guidelines or classification in these countries, although they could be included within the tertiary offer in Colombia. In addition, flexibility and the possibility of selecting different paths at various times stand out compared with the traditional model of a career with a general and broad content. Therefore, they can offer alternatives that promote adaptation to new trends. This suggestion could guide changes applied to the curriculum, such that students have a better adaptation: flexible vocational training with a focus on the development of skills.

Differences in the curricula respond to the historical needs of the selected countries in the analysis of the participation of the population in the educational system on the one hand (Table 4) and to the demands posed by recent technological changes on the other hand. Colombia focuses on solving its historical needs, such that its education policies target better student adhesion and permanence in addition to addressing the great disparity in access that exists in the rural population (OECD, 2018c). In this regard, the role of the National Training Service (SENA), an entity affiliated with the Colombian Ministry of Labor, in technical and technological training stands out with a wide offer, is free of charge for the population, and offers education for work according to the production needs of the country and its regions and sectors. Regarding the transformation of tertiary education, the diversification of education providers and new demands for skills in the market are leading to a transition from a highly academic education to a more diverse (but integrated) education to encompass all new trends (OECD, 2016).

Figure 3.
Educational system



Source: OECD (2019b)

Meanwhile, South Korea aims to move from a system focused on standardized knowledge to one that helps cultivate creative and integrative learners. This new vision aims to promote the flexibility and creativity that students employ to address the new challenges of the 21st century. The new proposal is that the educational system should transition from knowledge- to competency-based learning. These competencies include self-management, knowledge and information processing, creative thinking, aesthetic sensibility, communication skills, and civic competency (UNESCO, 2017). In addition to curriculum reforms, South Korea expanded its early childhood education and care system, increased financial and academic support for students with special needs, developed leadership paths, expanded teacher training, and restructured vocational training to better meet the needs of the labor market (CIEB, 2019a). South Korea intends to increase the interest and relevance of vocational education and training (VET) programs and to increase the emphasis on career exploration in the primary and secondary curricula. Moreover, the country is developing a national qualification framework for professional programs and is restructuring these programs to focus on specific industries to foster increased collaboration with industry partners. Moreover, it introduces Meister high schools modeled after the German Dual System.

In Germany, students traditionally settle in an academic or vocational line from an early age, although a few recent reforms delay the choice to increase the flexibility of students in making decisions (CIEB, 2019b). The German professional education system, which is better known as the Dual System, is highly recognized worldwide. It consists of a combination of theory and vocational training in a real work environment. The main feature of this system is cooperation between companies and vocational schools. Currently, approximately 330 occupations, which are recognized and certified by competent bodies, require formal training in Germany. The organizations and unions of employers are the ones promoting the creation and updating of occupational profiles and their regulation (Federal Ministry of Education and Research, 2019). In 2015, the most important future qualifications of employees were technical, practical, or specific skills for the workplace; customer orientation; teamwork; and general knowledge of information technology (IT; Destatis, 2019). This discussion illustrates a tendency for companies to give greater importance to the soft skills of employees and specific technical knowledge according to sector in addition to an inclination toward knowledge in IT.

Integration into the labor market

The third dimension considered in the comparative analysis refers to the degree to which the educational systems promote the incorporation of students into the labor market. The demand for people with a broad knowledge base and specialized skills continues to increase as globalization and technology continue changing the needs of global labor markets (OECD, 2019c). Table 5 provides several indicators that demonstrate a part of the situation. First, the unemployment rate (defined as people without work but actively seeking employment and currently available to start work) in Colombia (12%) is triple that of the rates of Germany and South Korea (4%). Although a low unemployment rate is observed for South Korea, the population entering the labor market (67%) is significantly lower than that for Germany (77%). Unemployment rates according to level of education in Colombia are higher for people with upper secondary and tertiary education, which could be the result of a mismatch between skills acquired at high levels of training and the labor market. Germany shows an inverse pattern, that is, low unemployment rates among people with higher education and relatively high unemployment rates in the population with less than upper secondary education. This result could be related to the link, which is favored by the Dual System, between the educational system and companies. Lastly, South Korea presents extremely low levels of unemployment at all levels of education.

Table 5.
Indicators of employment

Indicator		Colombia	Germany	South Korea
Employment rate, % of working age population (15-64; 2020)		64%	77%	67%
Harmonized unemployment rate (HUR) % of labor force (2020)		12%	4%	4%
Employment by level of education, % of 25-64-year-olds (2018)	Below upper secondary	71%	61%	65%
	Upper secondary, non-tertiary	75%	82%	72%
	Tertiary	82%	89%	78%
Unemployment rates by level of education, % of 25-64-year-olds (2018)	Below upper secondary	6%	9%	3%
	Upper secondary, non-tertiary	9%	3%	4%
	Tertiary	9%	2%	3%
Type of employment (2018)	Part-time (%of the employed population)	16%	22%	14%
	Self-employment (%of the employed population)	50%	10%	25%
	Temporary (% of dependent employment)	29%	13%	21%

Source: OECD (2019c)

In addition, a greater concentration of self-employment and temporary employment is observed in Colombia compared with those in Germany and South Korea, which denotes a lesser development of the supply of formal jobs. These types of jobs present high levels of restrictions and disadvantages in terms of social security, that is, they are less covered than formal workers. According to a report by the OECD2(019c), up to 75% for self-employed workers are less likely to receive any support when they stop working, and those who do, receive it in smaller amounts. This result leads to different challenges for the development of Industry 4.0 in the labor markets among peripheral countries compared to those in the core, especially during the post-pandemic context.

Adapting the education system to Industry 4.0: Similarities and differences

Each country has defined strategies for Industry 4.0. Germany and South Korea employ strategic or national objectives, whereas Colombia targets the improvement of the supply of knowledge.

Germany

The strategic initiative of the German government is called "Industrie 4.0," which was launched in 2011 and later developed (2013) as a platform that consolidates public and private actors, business associations, unions, and research organizations, to develop concepts and solutions, support companies, feed ideas in the Industry 4.0 discourse, and participation in international standardization processes (European Commission, 2020). One of the five working groups of the platform is "Work, Education and Training," which seeks to give recommendations on the design of "Work 4.0," create a social partnership in the industry, identify trends in qualification, create operational acceptance, and initiate networks of joint work between employers and employees (Platform Industrie 4.0).

One of the major characteristics of the German system is the role of companies in cooperation with educational institutions for the training of the next generations of skilled workers (BIBB —Federal Institute for Vocational Education and Training, 2015). According to the German model, the implementation of Industry 4.0 must be considered from the beginning in terms of how employees obtain (and maintain) the necessary qualifications. An interesting initiative is derived from the Chamber of Commerce and Industry (IHK), who developed the concept of a national training program called "Trainee for Industry 4.0 (IHK)," which seeks to sensitize young students to the necessary information about Industry 4.0 to meet the future needs of the industry. The program consists of seven modules with a minimum of 40 and a maximum of 64 course hours. Trainees experience an interdisciplinary understanding of digitization and acquire relevant skills and competencies in the area of Industry 4.0, such as the Internet of Things, and in the fields of application, businesses, processes, and tools (DIHK, 2019).

In general, the digital revolution, the study on occupational profiles, and actions that tend to accompany educational and VET models are issues that the country addresses across instances. These issues fall under one common strategy, which is defined in the platform created for this purpose, which seeks not only to maintain global leadership not only in the development of new technologies but also to place a strong emphasis on preparing students for the job market in collaboration with companies. This effort has taken a decade to be nearly complete.

South Korea

The Korean government developed the "I-Korea 4.0" policy brand for Industry 4.0. This plan was elaborated in 2018 and gave continuity to other plans developed in the country that pursue *informatization in Korea* (e.g., e-Korea in 2002 and u-Korea in 2006). The major strategies of this plan are intelligent technology innovation projects, secure technologies as growth engines, an industrial infrastructure ecosystem, and responses to future social changes. In the last strategy, one of the objectives is “innovate educational system in preparation for future social changes” (OECD, STIP Compass 2019; EU Cyber Direct, 2019).

The presidential committee on the Fourth Industrial Revolution (PCFIR) establishes the principles and coordinates the political strategy that defines the technological and scientific development of the country. The topics include artificial intelligence (AI) and data technology, as well as new industries and services necessary for the adaptation of the Korean society to the Fourth Industrial Revolution. It employs working committees under the abovementioned strategies, including PCFIR, which works on the innovation of educational systems for future social change.

Historically, South Korea designates a crucial role to education in creating value for the country, which has generated a great culture around the search for the best results in education for the entire population. One of the main modern features of the education system in South Korea is the “People-centered Education of the Future,” as stated by the Ministry of Education in their philosophy, with which they intend to strengthen education and promote human resources for creativity and convergence. Regarding this last aspect, the Korean Research Institute for vocational education and training (Krivet, 2017) mentions that “it is crucial to secure professionals that have the ability to develop smart information technology and apply it to a variety of industries, and the key challenge in this smart information society is how to reeducate and reposition those that are replaceable by automation.” On the necessary competencies for Industry 4.0, the country cites that competencies “include not only information technology, statistical analysis capabilities, and mathematical skills, but also cognitive and social skills such as listening and critical thinking, the ability to cooperate with others, and creativity.” Finally, they conclude that in contrast to technical skills, soft skills are hard to develop within a short period of time. Thus, innovation in the educational system is required.

Finally, another feature of the country is the focus on online education: for a long time, the country has sought to implement virtual education systems to cover the increased need for further training (the first cyber universities were created in a pilot in the year 1998). Korea Education & Research Information Service is a governmental organization under the South Korean Ministry of Education, Science and Technology, which develops, proposes, and advises on current and future government policies and initiatives regarding education in South Korea. It focuses on the development of information and communication technology (ICT) in educational systems. Today, even the most remote provinces of the country are provided with powerful computers and access to programs that digitally support school operations (Hochschulforum Digitalisierung, 2019).

Colombia

Even with differences in educational models, Germany and South Korea maintain educational strategies that share many points in common. In contrast, Colombia faces extremely different challenges as a developing economy, especially with reference to those on the frontier of industrialization. To follow up on new paradigms, Colombia employs a series of strategies and plans deployed through national plans and various public entities. Initiated by the Ministry of Education, The National Plan for Education 2016–2026 contains objectives, such as “include in the curricula the topics of the critical use and appropriation of technology, culture and the digital economy,” “promote the pertinent, pedagogical and generalized use of new and diverse technologies to support teaching, construction of knowledge, learning, research and innovation, strengthening development for life,” and “promote technology learning that meets the needs of different contexts and the new challenges of the digital society.”

The current National Development Plan 2018–2022 includes the Pact for the Digital Transformation of Colombia, whose main objectives include “bring the Internet to low-income households” and “improve interaction between public entities and citizens.” In addition, the Pact for Science, Technology, and Innovation seeks to adjust the regulatory framework “to take advantage of disruptive technologies and promote new industries 4.0,” among others. The ICT plan for 2018–2022 employs a strategy that aims to develop skills in human talent as required by the digital industry. It seeks to achieve the following:

> …educate and train different population groups in the country (children, youth and adults), which also includes the training of public-school teachers, university teachers, elementary and middle school students, university students and other people interested in learning from digital areas, and where spaces will be developed to strengthen the technical skills of people for the generation of digital content, applications and businesses.

Another digital talent strategy includes finding capabilities and productivity models for companies. Toward this end, it seeks to articulate initiatives from companies and academia to train a certain number of people with co-financing schemes from the ICT Ministry. Another example is the collaboration between the ICT Ministry, the Ministry of Education, and SENA, with training plans in emerging technologies such as AI, machine learning, and deep learning (MinTIC, 2019).

Additionally, the ICT Law (Law 1978 of July 25, 2019) aims for the following:

> …. align the incentives of the agents and authorities of the Information and Communications Technology (ICT) sector, increase their legal certainty, simplify and modernize the institutional framework of the sector, targeting investments to the effective closure of digital gaps and enhance the involvement of the private sector in the development of associated projects, as well as increase the efficiency

in the payment of the compensations and economic burdens of the agents of the sector.

Evidently, the plans mainly intend to address the large gaps in digitization in the country. In addition, a series of specific initiatives seek to train people in disruptive technologies.

According to a digitization analysis conducted by the OECD (2019a), additional measures are necessary to create educational opportunities for the population, improve offers in ICT specialization, promote schemes (e.g., such as the ICT School, that is, upper secondary education with a focus on ICT), and provide timely information on the labor market. The report states that “there is evidence that students take poorly informed decisions regarding what tertiary course to pursue.” Therefore, a transformation in the educational system that integrates the aforementioned programs and strategies is expected, such that the change is substantial and all learnings from the implemented programs can be consolidated and eventually lead to a mature country-level strategy. Finally, a topic worth highlighting is the role of Ruta N, a public joint venture of Medellín, as an institution that seeks to encourage innovation in cities. This venture is particularly related to the inauguration of the center and the talent strategy for the Fourth Industrial Revolution. This city is a key example of how a region drives this transformation, which is expected to be a network node that connects many initiatives that benefit the entire country.

Discussions and conclusions

The results demonstrate that the level of economic development and the core or peripheral position in global chains reveal significant consequences on the type of strategy that countries use to adapt and take advantage of the opportunities offered by Industry 4.0. This aspect is a significant challenge for Latin America given its inferior development conditions compared to other countries, such as Korea and Germany, which are ideal cases of countries that occupy a central position in the international context. Moreover, these countries possess a set of connectivity infrastructures and a degree of sectoral and functional specialization in the international division of labor. This differentiator enables them to propose educational strategies that clearly aim to maintain leadership in Industry 4.0 and limit the possible effects of this industry on job destruction (Brixner et al., 2020). Both countries have managed to guarantee universality in primary and secondary studies as well as in Internet access. Although they display differences in terms of the utmost importance that Germany gives to vocational education, the two countries offer various curriculum structures, which are characterized by a marked tendency toward flexibility in itineraries and a strong orientation toward the acquisition of skills related to Industry 4.0 (technical and soft skills). In the same manner, they effort to link training to work, especially in Germany, which is reflected in relatively low levels of unemployment. Lastly, educational strategies related to Industry 4.0 have been proposed more than a decade ago, which formed the central part of the educational agenda of both countries.

In contrast, the situation in Colombia is much more problematic in terms of taking advantage of the opportunities related to the development of Industry 4.0. The country maintains a strong specialization in natural resource-intensive activities, and it specializes in routine functions within manufacturing with low value added. Moreover, it continues to work to achieve universal access in primary and secondary studies as well as universal access to the Internet. The profile of university graduates is highly oriented toward careers, such as education and business, compared with those of Germany and South Korea, which concentrate their development toward engineering. In addition to the abovementioned aspects, the fact remains that the curriculum structures continue to be very traditional and limit the development of vocational careers that could take advantage of the application of Industry 4.0. Alternatively, self-employment and high levels of informality predominate in the labor market; even in the case of tertiary graduates, a lack of sufficient adjustment seemingly exists between training received and the needs of firms. This tendency illustrates shows that the educational system of the country is not aligned with the needs of a world undergoing full technological revolution, which significantly changes training needs to access jobs in the near future (OECD, 2019c).

In this sense, difficulty in adapting and taking advantage of Industry 4.0 is leading the country toward a technological catch-up that is seemingly limited. Perhaps, betting on niche strategies for Industry 4.0 while solving historical deficiencies that suppose the construction of a base before obtaining the desired capabilities is perhaps more appropriate. The abovementioned scenario also demonstrates the significant effect of the historical backwardness of the country in terms of education on its possibilities for growth and subsequent economic development (OECD, 2018a; Primi & Toselli, 2020).

Clearly, a new trend in higher education involves the development of skills for the development of new knowledge and solutions to social problems based on an intensive use of technology (Jimenez, et al., 2021). In this manner, the analysis of the study reveals the need to conduct further comparative analyses that highlight good practices and learning that have helped developed countries to take advantage of Industry 4.0. In addition, one must always keep in mind that solutions are not completely imitable and must be adapted to the extremely different realities of countries. In this sense, one of the limitations of this study, which may become a direction for future studies, is related to comparative analysis in its most qualitative aspects and to specific cases that could help countries, such as Colombia, to combine international good practices with specific aspects and needs within a country.

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