

Industry 4.0 Operators: Core Knowledge and Skills

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ABSTRACT

One of the most important technological changes due to the arrival of Industry 4.0, an initial, gradual, and complex process of technology transfer is taking place, which strongly relies on the integration of universities, industries, and governments. In this context, to make the Industry 4.0 approach a reality, several requirements need to be met. One of them is the need to qualify people to work in industries. This research paper aims to clarify the required knowledge and learning for a person to operate the manufacturing processes associated with some of the capabilities of Industry 4.0. Interviews were conducted with individuals who are Industry 4.0 employees, including experts of technology, education vendors, and employers who are eager to develop and improve their projects. This study provides several results, the most important of which is the focus on the rehabilitation of operators using modern technologies in alignment with the Fourth Industrial Revolution.

1. Introduction

The era we are living in these days is that of the digital revolution, which first took place the last quarter of the last century. This era is characterized by the fusion of all the techniques that have been developed, so that the physical, digital, and biological fields have overlapped, and the lines between them have blurred. Therefore, there was a need to move from the third revolution to a new one which is considered something unique. There are three reasons why these transformations are unique and not merely an extension of the previous revolution.

These reasons are: the speed of change, its scope, and the impact of these transformations on the prevailing systems. The speed of the current scientific breakthroughs has no parallel in human history, since there is an amazing speed in the development of digital technologies, compared to that of the previous industrial revolutions [1]. Hence, the Fourth Industrial Revolution is the impact of technology, the Internet, and computers on various sectors of development and labor, including material science, robots, nanotechnology, three-dimensional (3D) printing, unmanned aerial vehicles, digital computing, and globalization [2,3].

The Fourth Industrial Revolution is based on the digital revolution, in which technology is an integral part of the society and a link between the digital, physical, and biological worlds. It is characterized by the use of advanced technology in various fields to improve efficiency and promote development and growth [4].

The new mechanisms in the industry focus on technical education and the development of young people skills.

in different sectors of industry, which works to support the direction of political leadership in human development and devotes attention to human capital because this is the basis of any industrial revolution and development. Investing in the human workforce has become more important than ever before, as the world faces economic and social-environmental challenge [5].

The Fourth Industrial Revolution has added new pressures on the labor markets. Therefore, lifelong learning, learning reform, and new skill retraining initiatives will be the key to ensure that individuals have an effective economic opportunity to compete in the new world of work. Companies will also have the opportunity to attract the talented employees they need for future jobs. According to the World Economic Forum, at least 54% of all employees will need to be taught additional skills by 2022 [6]. Therefore, public and private sectors are required to hire new talented employees or train their employees to gain all the required knowledge to implement the latest technologies of Industry 4.0 Revolution.

The manufacturing industry is one of the sectors that are influenced by the fourth industrial revolution. Similarly, manufacturing is moved from Industry 3.0 phase into the Industry 4.0 phase. In industry 4.0 the manufacturing machines are connected to a virtual environment for each physical machine that presents the manufacturing process in real-time [7]. Therefore, factories are one of the entities that are encouraged to retrain and

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develop their operators to be able to gain all benefits of industry 4.0.

This research paper aims to clarify the required knowledge and learning for a worker to operate the manufacturing processes associated with some of the capabilities of Industry 4.0. This research focuses on operators whose factory is moving from Industry 3.0 into Industry 4.0. Interviews were conducted with individuals who work for Industry 4.0, including vendors of technology, education vendors, employers, and operators who work in factories capable of adopting Industry 4.0 technologies. This study provides several results, the most important of which is the focus on the rehabilitation of operators using modern technologies in alignment with the Fourth Industrial Revolution.

2. Literature Review

The influence of the educational system was obviously noticed through all the three industrial revolutions. Bryan Edward Penprase assures this point and adds that there were positive reactions in providing new educational tracks, majors, institutes for research in addition to new curriculums with the aim of preparing individuals [8]. The first industrial revolution was based on elective courses, enormous discoveries and inventions, centered on the use and adaptation of water and steam energy to the mechanization of productivity, including the gradual transformation of societies from their agricultural nature to a new identity. This new identity was characterized by industries that relied on steam engines, both for production, transport, and communication [9].

The second industrial revolution, from 1860 till 1900, was supported by educational institutes such as Pomona College (1887), University of South California (1880) and others to implement the new technologies to close the gap in operators and labor skills. The revolution was characterized by the use of electrical energy instead of steam and coal, which enabled countries with diverse natural resources to devote them to be exploited in the industry. This gave rise to industrial societies based on the principle of huge productivity. The emergence of electrical machines and their exploitation in peace and war was marked by very important inventions for the development of human civilization [10].

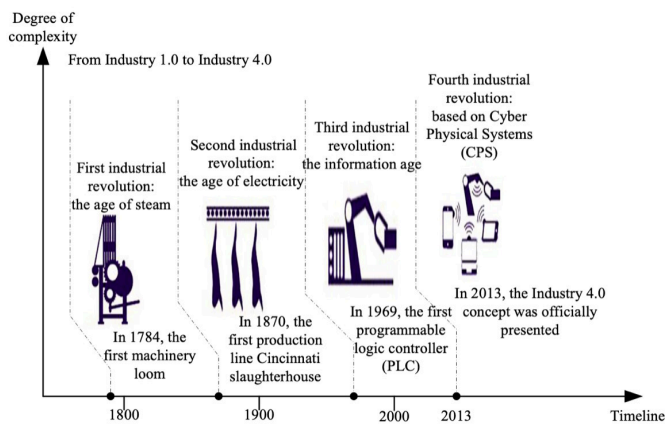


Figure 1. The four stages of the industrial revolution[11]

The third industrial revolution, during 1980s and 1990s, began with the launch of digital technology, such as computers and web-based sites on the Internet. The influence of this revolution was clear in two dimensions. These were the online based education

and new majors such as software development, engineering and automated manufacturing. Numerology was used in programming machines to function without the need to human supervision, causing machines to replace the labor force more extensively than the previous industrial revolutions, see figure 1 [11].

2.1. Industry 4.0 in manufacturing

The Fourth Industrial Revolution came with digital capabilities such as the digital-twin that were used in factories to read and analyze data of machines in real time. The revolution beginning was based on the remarkable achievements of the Third Industrial Revolution, particularly, the Internet and its uses, the enormous processing power, the ability to store and recall information whenever it is needed in addition to the unlimited potential for finding the required knowledge. Those achievements have paved the way to unlimited possibilities via the breakthroughs of emerging technologies in various fields. Those fields included many useful applications, inventions and theories such as: artificial intelligence (AI), robots, Internet objects, self-driving vehicles, 3D printing, nanotechnology, biotechnology, materials science, quantum computing, Blockchain, etc [12]. The Fourth Industrial Revolution, or the so-called Industry 4.0, simply means the intensive use of technology and advanced mechanization in the manufacturing processes, the activation of Internet objects, cloud computing, and robotization in the so-called Smart Factory.

The Fourth Industrial Revolution requires new skills such as data analysis and basic information technologies [13]. By these skills, the Revolution can have many impacts on business: Influencing customer expectations, product improvement, collaborative innovation, and organizational forms [11]. Regarding consumers' expectations or businesses, customers are always the centerpiece of the economy, which revolves around how to improve the process of customer service and satisfy them. Moreover, physical products and services can be improved through digital facilities that help increase the value. New technologies provide assets with better qualities and flexibility, while data and analysis change the way these assets are maintained. At the same time, the world of customers' feedback and the data-based services, asset the evaluation process through analysis, new forms of co-operation, especially the provided speed with which innovation occurs, the emergence of global platforms and other new business models which ultimately means that with talent, new culture and organizing methods will emerge [14].

The drastic shift from the simplicity of the Third Industrial Revolution to the innovation based on a combination of technologies (the Fourth Industrial Revolution) is creating a kind of pressure on companies to reconsider the way their businesses are progressing. One of the most experienced aspects of the recent Industrial Revolution (the 4th) is the concept of service-based design. This design is different from the factory settings regarding customers products and those products of companies for specific individuals, according to their specifications. On the other hand, this means that the new products will continue to be automatically and permanently produced by manufacturers [11].

The Fourth Industrial Revolution will affect people in many ways [15,16]. It will change what we do, what we are, and will also affect our identity and everything associated with it. For instance, our sense of privacy, property concepts, consumption patterns, and the time devoted to work and leisure, as well. Furthermore, it will also improve our skills and enhance our relationships. The feedback process for the manufactured products

will be self-explanatory, which will automatically help the manufacturer develop his manufacturing method.

2.2. Benefits and challenges of Industry 4.0

The mechanisms and tools of the Fourth Industrial Revolution reduce the operational costs of factories, improving the levels of corporate profits and the good employment of machines, as well as working to improve and raise the efficiency of human capital to cope with the flourishing era of advanced industry and manufacturing technology. The Fourth Industrial Revolution offers many opportunities for human societies to achieve higher rates of economic, social, and human development in general by minimizing the production costs and consequently providing services, transport, and communication, which combine high efficiency with lower prices. Other positive factors of Industry 4.0 include a contribution to better human healthcare as it shortens the time needed to the process of development, and easily disseminates its achievements throughout the world.

According to [17], the Fourth Revolution has a number of advantages. Three of these are:

1. The speed of its development at the rate of exponential growth, as modern a technology, always drives the development and the emergence of newer and stronger technology rather than the rate of a linear growth.
2. The increase in the volume of benefits per capita in this revolution is different. In the digital age, companies need a few number of employees and materials to manufacture products with great benefits and high qualities. For digital companies, storage, transport costs and product reproduction are reduced to zero level. Some technology-based companies are developing without large capital, e.g. Instagram, WhatsApp.
3. The coordination and integration of different discoveries is widely obvious in this Revolution. The profits of digital manufacturing technology and biotechnology have been shared. Recruiting designers and architects for digital design, implementing modern materials science, and industrial biology have increased the innovation and the production quality of modern products.

At the same time, Industry 4.0 imposes unprecedented challenges on human societies. Among these we find the following:

1. The dominance of large companies in industrial production and the threat of the disappearance of approximately 50% of jobs, which poses a challenge to the spread of unemployment, especially in countries that are not ready for the transformation process.
2. The possibility of employing the capabilities and advantages of the Fourth Industrial Revolution techniques in committing illegal or immoral acts that could harm society, values, or individuals, such as the growth of cybercrime, violation of privacy, spreading hatred, extremism and false news, and preventing the development of further global views.
3. Employees of factories who are moving from Industry 3.0 into industry 4.0 need to reskill themselves to utilize the benefits. This challenge relies on the effort of several stakeholders such as employers, vendors of technologies, and educational institutes.

2.3. Technologies of Industry 4.0

The Fourth Industrial Revolution works in harmony with three technologies: A) Physical technologies which are easily recognized, because they are concrete, such as self-driving cars, production line machines in factories, 3D printing machines, and sophisticated robots [14]. B) Digital technologies which create radically new devices, software and platforms that will revolutionize the way people and businesses conduct their dealings, namely, the IoT which can create the relationship between products, services, places, and people through related technologies and platforms [18]. C) Biological technologies: Industry 4.0 includes technologies to link humans to other technologies such as physical technologies. Currently, a machine can allow only operators who are eligible to work with it based on the operator's record in the factory human resources system [19].

2.4. Human Capital in Industry 4.0

Two of the most important possibilities of human capital are knowledge and education, where they support the Fourth Industrial Revolution to achieve the desired goals, which benefit institutions. The human capital theory believes that knowledge provides greater cognitive skills to individuals, thus it is necessary to impel their productivity and efficiency in a potential way to develop the related activities.

Certain education, experience, knowledge, and skillset have to be possessed by employees. As a result, these are used to create values regarding the success of an organization. Thus, we can see how experience, knowledge, skills, and education are critical for the human capital in organizations, which, in essence, underscore the importance and the role of the human capital in the Industry 4.0 revolution.

The requirements of Industry 4.0 are not only a workforce, but also human capital, nurtured in competitive education systems, which must be well prepared for creative work environments [20]. Nowadays organizations do not require physical and tangible humans as the present and future expectations seem to offer plenty of challenges to organizations and humanity. Therefore, as humans embrace the ushering in Industry 4.0, it has become imperative for nations, as well as organizations, to establish education systems that are more focused on knowledge which is beyond what the world currently addresses. This requires creative teaching particularly to children at early ages, right up to the university levels [21].

As modes of passing examinations never produce thinkers, creators, or ingenuity, there is a need to a new move away from the traditional education systems of writing, reading, and memorization. Therefore, nations need to revolutionize their education systems to produce super-humans capable of implementing the Industry 4.0 revolution. Educational revolutions require a national culture that is supportive of such initiatives of the government, where the citizens feel they have something to contribute towards achieving the goals of the Industry 4.0 revolution. Consequently, the result is the production of human capital that is capable of benefiting the Industry 4.0 revolution [22].

2.5. Education in Industry 4.0

Education based on Industry 4.0 is defined as technology literacy, information literacy, media creativity, social competence and responsibility, workplace skills, and civic engagement. This is

because the available information dramatically increases, therefore people are required to have new skills to critically access and process content to ensure the best social communication and interaction. The Industry 4.0 revolution presents an opportunity, as well as challenges, to nations' education systems, and only those nations whose education systems are anchored in inclusiveness and technological imperatives will remain competitive. To meet all of these demands for the Industry 4.0 revolution, lifelong learning is necessary to ensure that everyone can stay well-trained. Universities have to lead the research efforts not only to identify the relevant skills, but also to produce a high-caliber workforce that own the skills necessary for the Industry 4.0 revolution [23].

Barro [24] pointed out the importance of education and the accumulation of human capital, as well as their positive and moral impact on economic growth. In his study of 1991, he examined the determinants of the economic growth of a sample of 98 countries for the period 1960-1985 and concluded that the human capital has a significant direct effect on the economic growth. In his study of the impact of education on economic growth in 2013, he pointed out that applied studies were based on the neo-classical models of growth that were developed in the 1950s and 1960s. The variables of these models were often expanded to include government policies, institutions, and the accumulation of the human capital. In his 2013 study, he tried to emphasize the importance of his model of growth from to understand the possibility of maintaining long-term growth.

Besides, [25] pointed out that the 2030 Sustainable Development Plan and Goals emphasize the importance of education in promoting change in knowledge, skills, values, and behavior to achieve greater growth sustainability. The emergence of this concept was associated with the emergence of a need to a good educational system to deal with the increasing challenges.

Since the Fourth Industrial Revolution began to appear in the labor market, graduates have to prepared for it, and quality has to be achieved within the educational and research institutions in addition to applying an expansion of modern study disciplines. Curriculum development has become necessary to suit the Fourth Industrial Revolution, as well as enhancing the abilities and skills of students and faculty members in the field of scientific research and innovation.

3. Method

The chosen method was selected by the author based on his approach which was influenced by the phenomenological approach to sociology as it has been used in similar studies [26], [27] [28]. The method was chosen as it helps to understand all the required knowledge areas related to the 4th Revolution. To understand the required knowledge and skills for operators in the early adoption of Industry 4.0, interviews with individuals who work for Industry 4.0, including vendors of technology, education vendors, employers and employees (operators and managers) were conducted. It is believed that individuals who experienced the transition from Industry 3.0 to Industry 4.0 can identify the required skills and knowledge for the operators who are going to work in Industry 4.0.

3.1. Data collection

The interviews were planned, typed up, and arranged in a way that allowed for enough freedom in discussing related issues. An introductory question was developed to warm up the discussion and to let respondents provide important information. Additional

questions were prepared for cases where the respondent was not sure what was meant by the questions or if they fell short in answering a particular question. Permission to record and take notes was always obtained before an interview.

3.2. Data Analysis

The collected data from the semi-structured interviews were then tested thematically. Thematic analysis refers to the identification and analysis of patterns of meaning found in a specific set of data [29]. Specifically, it is a method used to identify, analyze and report patterns in the collected data, which helps to provide an organized, descriptive, and rich interpretation of those data. To correctly identify themes, the analyst needs to understand what counts as a theme. Themes grasp important aspects of the dataset that have a connection to the research question, representing a level of pattern or concept that is found in the analyzed data [30].

This research employed thematic analysis primarily for identifying, interpreting, and explaining the different aspects of the research topic. The adoption of this method in the research was due to its suitability for analyzing the collected data, concerning the research objectives. In addition to other advantages, thematic analysis was also an appropriate match to the research paradigm. To ensure a thorough analysis, the six steps proposed by [30] were followed. These steps are familiarization with the data, generation of initial codes, search for themes, revision of themes, definition, and naming of themes, and, finally, production of the report. The report shows the connections of the qualitative data in answering the research question.

The layered approach was used to strategically recruit participants that could provide us with insights into the required knowledge and skills for operators to work in an Industry 4.0 factory. The researcher interviewed technology vendors first because they would have had the experience of the new technology and the required skills needed for Industry 4.0.

Technology vendors provided comments about Industry 4.0 in general. While technology vendors explained their opinion about the general requirement of building Industry 4.0 solutions, the discussion was led to focus on the new skills required for operators to work with such technology. Moreover, technology vendors shed light on the essential features of Industry 4.0 and the skills required to gain the benefits of transitioning to Industry 4.0 or the quick wins of the transaction. Thus, the interview was led to a discussion on the required skills and knowledge for operators to work in factories that apply Industry 4.0. Furthermore, technology vendors provided stories about how technology has changed over time.

After clarifying the theme of the new technologies of Industry 4.0, participants who had been involved in working in factories that apply some of the Industry 4.0 technologies were recruited. In the second round, people of different positions on the employer side, starting with a chief Executive Officer (CEO) of a rigid plastic factory were interviewed. Lastly, participants from education vendors that have programs for preparing operators to find the missing knowledge in traditional operator programs and the required knowledge and skills for Industry 4.0 operators were recruited.

The first round consisted of eight interviews of technology vendors and was conducted in the summer of 2017 to find the required knowledge and skills for being an operator in Industry 4.0.

The second round consisted of 17 interviews that aimed identify the required knowledge and skills for Industry 4.0, based on the feedback of users and employers of Industry 4.0. The users and employers applied the essential basics of Industry 4.0, such as connecting the machine and starting it, to automatically retrieving production data from the machine immediately. These users are those who, for instance, use manufacturing execution systems to show dashboards for data that are retrieved from the machines directly.

The last round consisted of interviewing educational vendors that teach and prepare operators to work in manufacturing. Educational vendors, who are designing new courses to bridge the gap between Industry 3.0 and the early features of Industry 4.0 (e.g., such as data visualization and connecting production machines), were chosen. This round consisted of interviewing eight participants. In total, 27 individuals were interviewed in person and six over the phone, all of whom had been involved in Industry 4.0 in many different capacities (see Table 1 for a partial list).

Table 1. Selected interviewee roles.

Title	Number of interviews
Factory CEO	1
Factory manager	1
Production manager	1
Operator	3
IoT manager and leader	3
Industry 4.0 pre-sale architectures	3
Program coordinator	1
Instructor	2

3.3. Themes

The collected data were carefully reviewed, looking for the barriers, challenges, and difficulties addressed by respondents, either implicitly or explicitly. The findings were coded and clustered into main and sub-categories. The issues, concepts, and patterns were re-categorized, and refined.

Among the several steps taken to analyze the collected data, the interviews were revisited to find and list all of the mentioned challenges, which were then organized into a list. The list was then refined, excluding repeated issues and combining similar challenges. Similar basic issues were clustered to form organizing themes.

This step reduced the list into organizing themes, which were then combined under wider classifications. The themes are discussed underneath.

The first round of interviews targeted the Industry 4.0 solution vendors. Firstly, the focus of the interviewees was shifted to the new IT capabilities to be added to factories as required competencies for Industry 4.0. These capabilities include edge connectivity, cloud solutions, and microservices. Additionally, there are certain prerequisites, such as the ability to connect a production machine and the availability of process and production sensors.

However, the focus of this research was on the operators. Therefore, the interviewer led the conversation to focus on the new set of skills required for Industry 4.0 operators. After clarifying

these concerns, the technology vendors started by stating the tools and solutions, focusing on Industry 4.0 operators, as follows:

One of the essential features of Industry 4.0 is its digital twin. A digital twin is a digital replica of a living or non-living physical entity. By bridging the physical and the virtual world, data are transmitted seamlessly, allowing the virtual entity to exist simultaneously with the physical entity. Operators will be able to obtain different sources of manufacturing data, beyond what their old friend, the human-machine interface (HMI), could provide them with. The digital twin in Industry 4.0 can provide real-time data for the targeted machine and can compare it with similar machines or the process and production data of the same machine historically. Operators need to have essential knowledge of data science activities. These activities include data analysis, descriptive analysis, and problem-solving [7].

Technology providers have industrial platforms that empower users to use and rebuild micro services with minimum programming knowledge. Predix by General Electric (GE) and MindSphere by Siemens are examples of these platforms. Operators will gain access to such technology and could develop basic services for their common issues. These microservices do not require advanced programming skills to be utilized by an operator; however, basic knowledge of programming, web development, and problem-solving are required for operators who want to run the extra mile and develop their tools.

On the other hand, operators work closely with the operational technology that is provided on the machine side. Industry 4.0 will allow operators to access real and historical manufacturing data from different resources. Therefore, operators need to have the ability to work with IT solutions, such as manufacturing execution systems.

The second-round targeted employers and business owners that recently empowered some of their production lines with Industry 4.0 tools and solutions.

The first concern of an employer (a production manager) was that the operators will remain essentially the same. The operators will not be developers for Industry 4.0, but they will need to know how to work and use Industry 4.0 tools. The operators will still need to have the essential instrumentation and process knowledge. However, they will have access to new tools that will help them to improve the productivity of their machines. An example of a new tool is historian trends. This is an analytical tool that allows users to present different process data in one dashboard to analyze a certain issue, such as major downtime.

Surprisingly, a CEO and one of the production managers stated that the English language is important for empowering operators to get the most from Industry 4.0 tools and solutions. The available knowledge and most of the provided solutions are available only in English.

On the other hand, IT literacy is another important prerequisite for operators to utilize Industry 4.0 tools and solutions. IT literacy is different from digital literacy or informatics literacy/computer science literacy, as it puts more emphasis on computer programming, algorithms, and other important mathematical and computational concepts. IT literacy includes an essential area, such as information management, integrated system technology, platform technology, and system paradigms.

The last round consisted of interviews with educational institutions. All of the interviewed educational institutions had an ongoing contract involving the training of operators for local employers. One institution had contracts with food and beverage packaging manufactures and two had contracts with petrochemical, oil, and gas industries. The first theme introduced by the institution members was the IoT. New operators will work on machines that are connected to edge or cloud computing services. The existing sensors in the machine or the new ones will have the same concept of the IoT. Operators will be introduced to the concept of IoT and how platform technology can help. This new theme works smoothly with most of the industrial platform microservices, which are developed to interact with the physical assets to provide better information for operators and the rest of the factory team.

Similar to technology vendors, the interviewees from the educational institutions listed the following concepts to be added to the required skills of Industry 4.0 operators: (1) Basic programming and problem-solving, (2) web development and advanced analytical skills, and (3) basic data science activities, such as anomaly detection. Additionally, IT literacy is a topic that is required by all three different stakeholders. Table 2.0 lists all of the common required knowledge areas, as indicated by all of the stakeholders.

The educational institution interviewees agreed that operators are required to know about programmable logic controllers (PLC), instrumentation, process control, and automation. However, these are not new, and there are diplomas for operators.

In summary, the results from all of the interviews could be organized into two main categories:

1. Operation technology categories which include PLC microcontrollers, pneumatics and hydraulics, and industrial instrumentation.
2. Information technology (IT), which is the goal of this study and identifies the missing knowledge for Industry 4.0 operators as follows: digital industry platform; computer skills and information technology (IT literacy); data analytics and visualization; basic programming and problem-solving skills; introduction to web development; and industrial IoT.

4. Results and Discussion

According to the conducted interviews, the study provided several results, including the following:

It is necessary to have certain knowledge for operators working in factories adopting industry 4.0. Moreover, it is not a must that the required knowledge should be of a high level. This knowledge can be provided in vocational and technical institutes that offer a two-year diploma after finishing secondary school. This was clear in the interview with one of the interviewees who mentioned that a few number of courses can be added to the current ones at vocational institutes. The new added courses, which match the conditions of the work fields, are attractive factors to students at the vocational institutes. Those students chose to study there as their GPA at secondary schools did not enable them to join universities but on the other hand, gave the chance to get a good job immediately after finishing their diplomas.

Table 2. Selected interviewee roles.

Stakeholder Title	Recommended Course/Knowledge
Technology Provider	<ol style="list-style-type: none"> 1. Programming and web development foundation 2. Industrial platform technologies 3. Analytical tools and problem-solving skills
Educational Institution	<ol style="list-style-type: none"> 1. Information and communication technology 2. Programming and web development foundation
Employer	<ol style="list-style-type: none"> 1. Information and communication technology 2. Human-machine interface (HMI) 3. Programmable logic controllers (PLC) 4. Instrumentation 5. Process control 6. Automation 7. Familiarity with technology 8. Programming and web development foundation 9. Data science

Furthermore, the results shed light on the role of the private sector firms in supporting the 4th revolution. One of the interviewees has mentioned that the institute was established by several companies, and added that the courses to be studied are related to the future needs of those companies.

Many modern technologies must be available to suit the Fourth Industrial Revolution, including edge connectivity, cloud solutions, and microservices. Additionally, certain prerequisites must be met, such as the ability of a production machine to be connected and the availability of process and production sensors. The operator is one of the most important factors supporting the Fourth Industrial Revolution due to the fact that he/she, in most cases, is the first user of industry 4.0 products rather than developers or designers. Consequently, he/she must be rehabilitated and trained for that purpose.

The required knowledge can be achieved through:

1. Basic knowledge of programming, web development, and problem-solving, which are required for operators who want to run the extra mile and develop their tools.
2. The ability to work with IT solutions, such as manufacturing execution systems.
3. Mastering the English language, which is important to empower operators to get the most of Industry 4.0 tools and solutions.
4. IT literacy, which is an important prerequisite for operators to utilize Industry 4.0 tools and solutions.
5. Knowledge of PLC, instrumentation, process control, and automation.

6. Knowledge of digital twins (one of the essential features of Industry 4.0). A digital twin is a digital replica of a living or non-living physical entity. By bridging the physical and the virtual world, data are transmitted seamlessly, allowing the virtual entity to exist simultaneously with the physical entity. Operators will be able to retrieve different sources of manufacturing data from those which their old friend, the human-machine interface (HMI), provided them with. The digital twin in Industry 4.0 can provide real-time data for the targeted machine and can compare it with similar machines or the process and production data of the same machine historically.
7. Essential knowledge of data science activities. These activities include data analysis, descriptive analysis, and problem-solving.
8. Knowledge of how to work and use Industry 4.0 tools, without being a developer for Industry 4.0.

5. Conclusion

In light of the rapid changes in financial, economic, political, and social systems, our world is on the threshold of a Fourth Industrial Revolution, which will not only change the form of industries and the methods of production but will impose new requirements on humans. This research paper provides strong evidence of the importance of the role human capital plays in the Industry 4.0 revolution in which the success or failure of most organizations largely depends on how their human capital is managed. This is because the Industry 4.0 revolution provides a space where employee-machine interactions are the order of the day. There is an interconnectedness among the various players and actors. The interfaces created to become the connecting points between workers and machines. The features of the Industry 4.0 revolution require creative and inventive workers i.e. those who are not just creative but are also knowledgeable and have the technical expertise required to work in such environments. Such workers are nurtured through an education system, where creativity, inventiveness, knowledge, and technology flourish and are entrenched in the national culture.

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