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This document is a literature review on industry 4.0. The objectives of this deliverable are as follows
- provide a definition of the main concepts related to industry 4.0
- describe existing competency concepts and models
- analyze these models and their application in HEIs

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1. Introduction

This report aims to review literature related to the latest concepts, models, and infrastructures for manufacturing in the revolutionary Industry 4.0 for a comprehensive understanding of the challenges, approaches, and used techniques in this domain.

Industrial production is nowadays driven by global competition and the need for fast adaptation of production to the ever-changing market requests. Companies are striving to produce the best compelling products/services with the highest customizability and lowest cost possible. These requirements are met by the radical advancement in the industrial department. Industry 4.0 seems to be a promising solution that could revolutionize the current industrial ecosystem, and push development to the next level.

This radical advancement is mainly due to technologies underlying Industry 4.0. Due to the recent advancement of Information and Communication Technology (ICT), Machine-to-Machine (M2M) communication, and Wireless Sensor Network (WSN), new technologies such as Cyber-Physical Systems (CPS), Internet of Things (IoT), and Internet of Services (IoS) are emerging to achieve effective automation and connected world. Eventually, the revolutionary concept of Industrial Internet [1,2] of US initiative and its German counterpart Industry 4.0 [3,4] evolves drawing together the CPS, IoT, and IoS [5-8] concepts. The initiative for Industry 4.0 proposes a highly networked and flexible ecosystem for the latest production control systems [9].

In recent years, industries have incorporated mobile, desktop, and web interfaces along with new multi-touch interaction modalities [10,11]. In any of the interfaces, agents attached to different machines and processes communicate with each other to achieve interoperability [12] through Multi-Agent Systems (MASs) [13,14]. In addition, the “collaborative automation” paradigm [15] helps to achieve flexible, scalable, reconfigurable, interoperable, and network-enabled collaboration between dispersed embedded systems. These factors lead to a new dimension of industrial architecture with industrial CPS [16]. There are a number of projects SOCRADES [17], IMC-AESOP [18], GRACE [19], ARUM [20], etc. to address these issues.

These technologies related to Industry 4.0 will have a significant impact on current industries and the construction of industries of the future. Companies in the developed world are already on their way to fully embracing the concept of Industry 4.0 and are starting to see significant results. However, in order to achieve that, major changes and updates should be made to a company’s Business model, reference architecture, and industry ecosystem. Companies willing to carry out a transition to a digitally integrated production model proposed by Industry 4.0 should evaluate their skills and adapt their strategies to implement them in the appropriate scenarios.

The overall objective of this deliverable is to detail the different constituents of Industry 4.0 and the changes it brings to companies' ecosystems, as well as shed light on the role and importance of educational institutes in the transition process.

2. Industry 4.0

Industry 4.0 (shortly called I4.0 or I4) refers to the *"Fourth Industrial Revolution"* that's the new digital industrial technology for transforming industries into smart/ intelligent industries *(iIndustry)* by connecting machines with intelligent robots [1, 2, 3]. It engenders and analyzes data across the machines to produce high-quality products at low costs and changes traditional production relationships among suppliers, producers, and customers. Industry 4.0 amalgamates nine technologies to transform industrial production, which include: (1) Big Data Analytics, (2) Autonomous Robots/ Robotics, (3) Simulation, (4) Horizontal & Vertical System Integration, (5) Industrial Internet of Things (IIoT), (6) Cybersecurity, (7) Cloud Computing, (8) Additive Manufacturing (such as 3-D printing), and (9) Augmented Reality (shown in Fig. 1) [4, 5]. Industry 4.0 uses Decision Support Systems (DSS) incorporating knowledge mining techniques to know what actions need to take in the future that help manufacturers to optimise their operations quickly [6]. The fourth revolution ameliorates the industries with intelligent computing fuelled by data with Machine Learning (ML) and Data Mining (DM). Industry 4.0 connects machines with the Internet of Things (IoT) devices to make decisions without any manual intervention. This essentially means that Industry 4.0 is the network of machines that are digitally connected with each other and share information, which makes the industries more productive, efficient, and less wasteful [7, 8, 9].

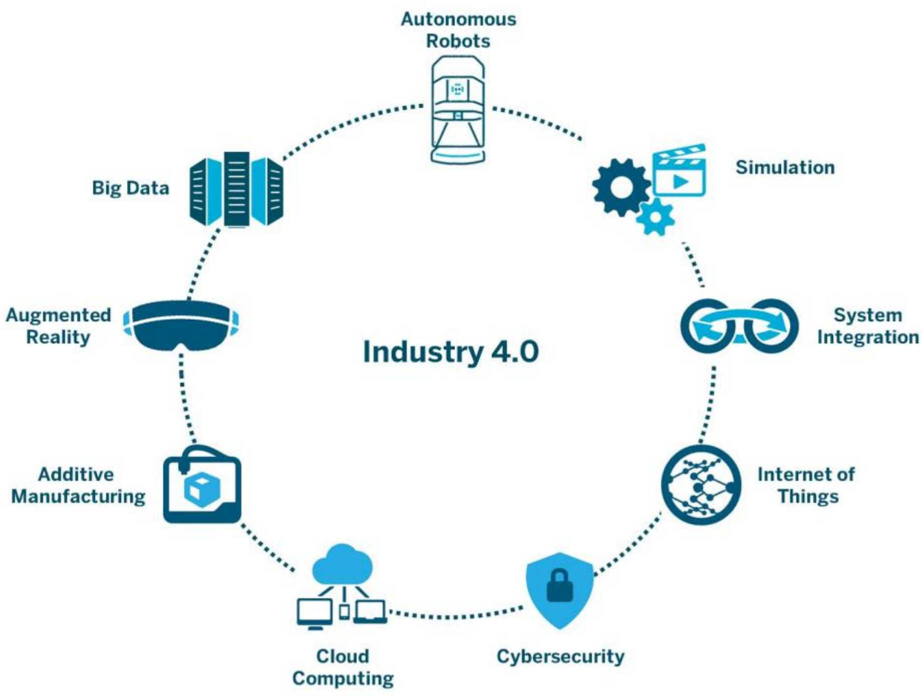

Figure 1: Industry 4.0 Technologies.

The first Industrial Revolution (Industry 1.0) was started in 1784 when the first weaving loom was introduced. The revolution led to the mechanical production of the goods including weapons, tools, food, clothing, and housing to the world using water and steam power. At the time people witnessed mechanization that resulted in massive changes in operations such as human hands were replaced by water and steam-powered machines, and the farms were transformed into factories for increasing production quality, efficiency, and scale.

Following the first industrial revolution. almost a century later that is, in 1870, the second industrial revolution (Industry 2.0) introduced machines with electrical energy as electricity is considered the primary source of power. In Industry 2.0, the electrical machines took the place of the water and steam-based machines for the mass production of goods. Also, the concept of assembly line and several production management techniques were introduced in this era.

In 1969, Industry 3.0 (Information Technology (IT) & Automation) introduced computers and electronics within the operational landscape of industries. The revolution gave rise to electronics, telecommunication, and of course computers. In the world of industries, the programmable logic controllers (PLCs) and computers helped to lead to an era of high-level automation. The PLCs and computers were used to automate an entire production process without any human assistance for mass production of goods with quality; for example, using programmable robots in industries.

In 2011, Industry 4.0 is introduced in Germany by the “High-Tech Strategy 2020” project [10, 11]. The vision is to consider the entire network formed by computers and machines rather than considering them isolated. They are supposed to be prone to communicate each other and to share information in order to make decisions without any human involvement. Industry 4.0 transforms industry into *iIndustry* using new technologies like the Internet of Things (IoT), Big Data, Artificial Intelligence, and Machine Learning. In Industry 4.0, the machinesand IoT devices are producing a huge amount of data and , therefore, advanced Data Mining tools & techniques are required to analyze the data so that the system can predict the future events[12, 13]. For example, with predictive maintenance capability, the system would be able to predict mechanical faults in machines which could proactively be replaced/ fixed -; the predictive analytics enables a system to predict anomalies in the supply chain management (SCM) process [14]. Fig 2 shows the fourth industrial revolution.

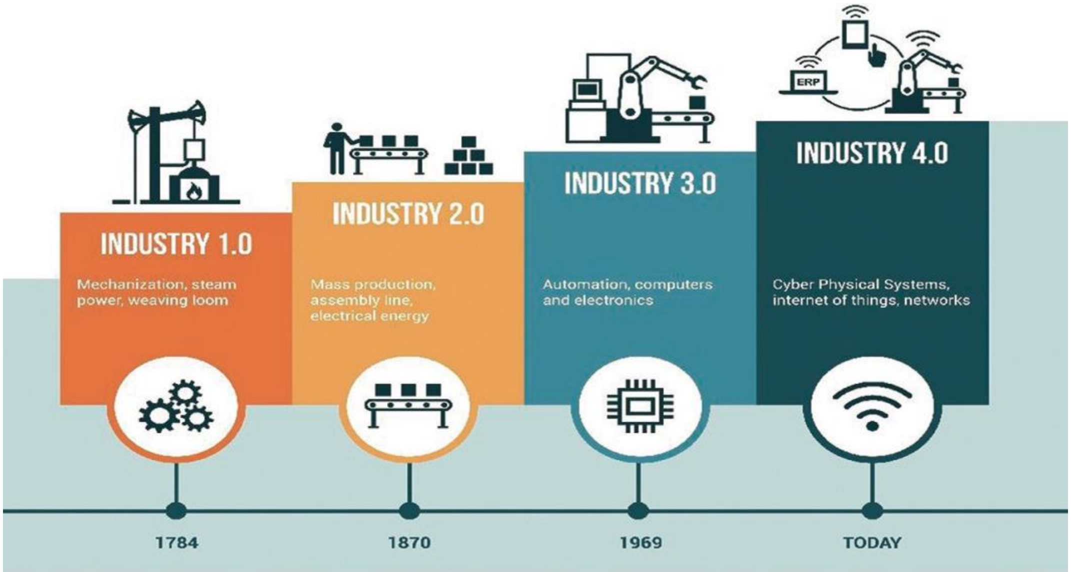

Figure 2: The Fourth Industrial Revolution.

In 2020, Bu ̈chi et al. [15] investigated the relationship between the concepts of openness and performance in Industry 4.0. The level of openness to the pillars of Industry 4.0 technologies was evaluated based on the number of technologies used; and the number of value chain stages involved. On the contrary, the performance of Industry 4.0 was estimated by the extent of opportunities business obtain. This study analysed and developed regression models based on the survey data of 231 local manufacturing industries that developed the Industry 4.0 concept in Piedmont (northern Italy); the dataset was collected in the year 2018. The results revealed the opportunities of openness toward Industry 4.0 to achieve higher possibilities in terms of increased production capacity, flexibility, speed, decreased errors and costs, and ameliorated product quality and the ability to encounter customer requirements.

Knowledge extraction for decision-making from the previously generated information is one of the major issues to design and develop effective production systems (PSs) in Industry 4.0. In 2020, Doltsinis et al. [6] proposed an online Decision Support System (DSS) using the Industry 4.0 Cyber-Physical System (CPS) design principles for boosting production that also support offline leaning using previously gathered knowledge. The findings of this study indicated that supporting human agents with DDS during the production process significantly reduces the number of steps and the required time. In 2019, Annosi et al. [16] highlighted several advantages of using 4.0 technologies for agricultural Small & Medium Enterprises (SMEs). This study discussed different types of applications of the 4.0 technologies for agricultural SMEs, e.g., smart irrigation, agriculture drones (Unmanned Aerial Vehicles (UAVs)), soil & plant monitoring systems, precision livestock systems, and smart greenhouses, etc. The authors collected survey data from 96 Italian agricultural SMEs that investigated the investments and adoption of digital applications for improving the firms' products or processes. This research found that the use of 4.0 technologies in agriculture brings several benefits to agricultural SMEs, in terms of increased yields, reduced costs, bigger profits, more information for better decisions, and sustainability.

2.1 Industry 4.0 Technologies

In this digital era of the Internet of Everything (IoE), Industry 4.0 amalgamates nine technologies to transform the industrial production for changing traditional production relationships between suppliers, producers and customers [17, 18]. In this subsection, we discuss each of the nine technologies that form the building blocks of Industry 4.0.

2.1.1 Big Data Analytics

Big Data analytics/ mining is the process of extracting knowledge and uncovering hidden patterns from the extremely large volume of data sets to understand the current and future trends [19, 20, 21]. Big Data mining is one of the major technologies in Industry 4.0 to lucid market trends, customer preferences, and other information that's useful to businesses [22]. Big Data analytics support real-time decision making for building smart factories or *iIndustries* in Industry 4.0 [23]. Data is the individual units of information or collection of facts, such as numbers, words, measurements, observations, etc., that stored in computers. Generally, Big Data refers to 3 V's: (1) Volume, (2) Variety, and (3) Velocity [24, 25], which is shown in Fig 3. In Big Data, the volume of data is extremely large that cannot be stored in a single computer/ memory. Therefore, mining Big Data is a challenging task. It needs parallel and distributed computing capability. . Variety of data is another critical concern in Big Data. Variety includes different types of data including numbers, characters, strings, images, video, audio, etc. The real-life Big Data is high-dimensional too, and most of the time there is a strong correlation among the input features [26]. In this digital era of the Internet of Things (IoT), globally, the users are generating about 2.5 quintillion bytes of data every day and is expected to reach 44 zettabytes of data by the end of 2020. The IoT data are streams that move with high velocity within and across of an industrial solution ecosystem. The characteristics of streaming data can be changed over time, for example, concept drifting in a data streaming environment [27, 28]. In addition to the 3V's, more characteristics were introduced which are follows: veracity which means uncertainty, Vision refers to having a purpose/ plan, Verification means ensuring that the data conforms to a set of specifications, and Validation is a process of checking that the purpose of data is fulfilled [25].

Nowadays, machine learning (ML) is one of the major tools and techniques for mining Big Data [29]. However, the traditional ML classifiers are designed and developed for mining a relatively small amount of data [26]. Hence, more scalable and robust ML algorithms are required to extract meaningful insights from Big Data; RainForest and BOAT (Bootstrapped Optimistic Algorithm for Tree construction) [30] are examples of the scalable algorithm. Typically Big Data can be imbalanced where majority class instances influence over minority class instances. Existing ML algorithms tend to correctly classified majority class instances, and misclassify minority class instances [31]. Also, labeling unlabelled data in semi-supervised learning is a difficult task, and selecting informative instances (both majority and minority class instances) are important for boosting up the performance of ML classifiers for mining Big Data [32]. It's also necessary to find the similarities between the instances in Big Data, and clustering Big Data can be very useful for building optimal ML classifiers [33].

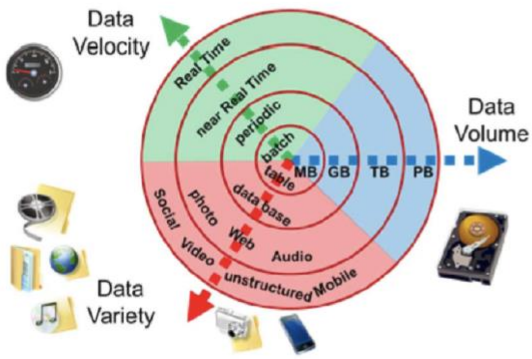

Figure 3: Big Data 3V's: Volume, Variety, and Velocity.

Big Data along with IoT technologies are vital in Industry 4.0. In 2020, Sahal et al. [34] explored open-source big data technologies, including massive scale stream processing platforms, distributed message queue management systems, big data storage platforms, and streaming SQL engines for Industry 4.0 requirements mapping for predictive maintenance (PM 4.0). The authors found that Big Data analytics reduce operation and maintenance (O&M) costs in PM 4.0. This study discussed the open-source technologies for building a big data-driven end-to-end solution pipeline including data collection, storing, analysis, and querying. Tiwari et al. [35] reviewed the effect of Big Data analytics research and application in supply chain management between 2010 and 2016. This study surveyed the techniques for data collection, data organization and analysis of data to present valuable insights in Industry 4.0 by discussing the role of big data analytics in supply chain management (supply chain analytics). It is necessary and plays an important role in Industry 4.0 to apply Big Data tools and techniques to deal with an increasing number of data in supply chain management for decision-making. Wang et al. [36] proposed a multi-agent-based framework for self-decision making and intelligent negotiation mechanisms to build smart factories by integrating the autonomous agents with Big Data mining-based decision support system. This study focuses on two aspects: modeling the smart shop-floor objects such as machines, conveyors, and products as intelligent agents to negotiate mechanisms for them to cooperate with each other, and to prevent the deadlocks by improving agents' decision making and the behaviour of coordinators. Big data analytics is a principal component in smart manufacturing frameworks. Data analysis and management using Big Data tools and techniques ameliorate manufacturing intelligence that can take timely and accurate decisions.

2.1.2 Autonomous Robots/ Robotics

Industry 4.0 Robotics plays a principal role in the modern manufacturing industry, which refers to industrial manufacturing processes where all equipment and devices are connected with intelligent robots/ computers to ameliorate productivity, engender high-quality products and reduce the costs of productions [37]. Programmable Logic Controllers (PLCs) were introduced in Industry 3.0 which was essentially the beginning of industrial automation. Intelligent robots are replacing humans in *iIndustry*, in some cases robots are performing tasks (e.g., packaging & labeling, painting, assembly & disassembly, product inspection & testingg, mechanical cutting, grinding, and polishing, etc.) without any human assistance; even robots fixing the problems of other robots nowadays. Bahrin et al. [38] reviewed the applications of robotic and automation technologies in Industry 4.0 for smart factories and smart production. This study illustrated the use of several kinds of robots in Industry 4.0.

Industry 4.0 is becoming the de facto paradigm for improving product quality, speed of production, customisation of products, for which autonomous robots is turning to be an indispensable technology within industrial solution landscape. Generally, industrial robots are classified into six clusters based on mechanical configuration: (1) articulated robots, (2) cartesian robots, (3) selective compliance assembly robot arm (SCARA) robots, (4) delta robots, (5) polar robots, and (6) cylindrical robots. Industrial robots can be classified further based on other criteria such as motion control, power supply control, and physical characteristics. Articulated robots resemble a human arm in its mechanical configuration that is the most commonly used industrial robot for packaging, painting, metal casting, and other industrial applications. The arm is connected to the base with a twisting joint in an articulated robot. The number of rotary joints connecting the links in the arm can range from two joints to ten joints and each joint provides an additional degree of freedom. The joints can be parallel or orthogonal to each other and having six degrees of freedom. Cartesian robots are known as rectilinear/ gantry robots having a rectangular configuration for rotational movement and a prismatic joint for linear motion. These types of industrial robots have three prismatic joints to deliver linear motion by sliding on its three perpendicular axes (X, Y & Z), and mostly use in industrial applications as these robots are easy to configure and make them suitable for specific industrial applications. SCARA (Selective Compliance Assembly Robot Arm) robots have two parallel joints that provide compliance in one selected plane. SCARA robots have rotary shafts that are positioned vertically, and the end effector attached to the arm moves horizontally. It can move faster than cartesian robots. Delta robots are known as parallel link robots used for manufacturing in the food, pharmaceutical, and electronic industries, it consists of parallel joint linkages connected with a common base used for fast pick-and-place or product transfer applications. Polar robots are called spherical robots, having a twisting joint connecting the arm with the base and a combination of two rotary joints and one linear joint connecting the links. These robots have a centrally pivoting shaft and an extendable rotating arm. The gun turret configuration of polar robots sweeps a large volume of space, but the access of the arm is restricted within its workspace. Cylindrical robots have at least one rotary joint at the base and at least one prismatic joint connecting the links. These robots have a cylindrical workspace with a pivoting shaft and an extendable arm that moves vertically and by sliding. Cylindrical robots used for assembly operations, handling machine tools, spot welding, and handling at diecasting machines. In Industry 4.0, Human-Robot Interaction (HRI) is becoming one of the major research topics to understanding, designing, and evaluating robotic systems that require communication between robots and humans. HRI received considerable attention in the intelligent computational research community and also experts from Industry 4.0 recently. Because, it enables flexible production in *iIndustry* to rapidly changeover production lines to shorten lead times.

2.1.3 Simulation

Industry 4.0 Simulation helps smart factories in several ways by designing products, time management, increasing productivity and efficiency in manufacturing, and generating revenues in this new industrial age [39, 40]. The role of simulation in Industry 4.0 and the simulation optimisation in the era of Industrial 4.0 promoted a new line of research to the practitioners and researchers. Simulation imitates the process of a system to show the eventual real effects of system operation over time. A system should be tested very carefully before the application of a new paradigm. Several types of simulation including discrete events and 3D motion simulation can be performed in various cases to improve the product or process planning. E.g. simulation can be adapted in product development, test & optimisation, production process development, and optimisation. In the era of Industry 4.0, simulation can be evaluated as a support tool to follow the reflections gathered from various parameter changes and enables the visualisation in decision making. Therefore, the use of simulation tools is critically important especially for Industry 4.0. Nowadays, computer simulation has become an effective technology of Industry 4.0. Computer simulation helps to create model a real-life situation on a computer so that it can be studied to see how the system works. The behaviour of the system can be observed by changing parameters. Simulation handles the complexity of industrial systems and provides a strong real-life decision-making methodology by incorporating the information.

2.1.4 Horizontal & Vertical System Integration

Horizontal and vertical system integrations are blueprints for building *iIndustry* in Industry 4.0 that used by businesses in the same industry or production process. Horizontal integrations help *iIndustry* to expand in size, diversify product offerings, reduce competition, and expand into new markets. It's a business strategy where a company takes over another that operates at the same level of the value chain in an industry. On the other hand, vertical integrations involve the acquisition of business operations within the same production vertical. It can help to boost profit and allow smart factories more immediate access to consumers.

2.1.5 Industrial Internet of Things (IIoT)

The Industrial Internet of Things (IIoT) refers to Internet 4.0 (Industrial Internet) or the Internet of Everything in Industry 4.0, which has become one of the most important research areas for building *iIndustry* nowadays. IIoT is a system that amalgamates computing devices, sensors, instruments, and other devices in a network to transform business operational processes, including manufacturing and energy management into knowledge for accelerating productivity in industries [41]. IIoT engenders a large volume of data, and uses cloud computing and Big Data analysis tools and techniques to optimise the process controls and reduce unplanned downtime.

The IIoT applies several technologies such as cybersecurity, cloud computing, edge computing, mobile technologies, machine-to-machine (M2M), 3D printing, advanced robotics, big data, internet of things (IoT), RFID technology, and cognitive computing. For example, with Big Data in IIoT systems, large-volume of streaming data generated by IIoT system can be stored in cloud storage systems and mining the data in the cloud to extract knowledge for building decision support system (DSS) to boost the productivity and efficiency, and reduce the operational costs. In 2020, Younan et al. [42] reviewed the state-of-the-art challenges of IIoT in device level, network level, and data level, and recommended the IIoT framework for Big Data mining and analysis. Also, this study surveyed IoT search engines (IoTSEs) and presented two case studies for reflecting amelioration of intelligent IoT applications in Industry 4.0. In 2019, Garrido-Hidalgo et al. [43] proposed an end-to-end solution for Reverse Supply Chain Management (R-SCM) based on cooperation between different IoT communication standards, enabling cloud-based inventory monitoring of WEEE through embedded sensors. In this study, a case was introduced applying IoT devices & sensors for carrying out a set of experiments focusing on wireless communications to evaluate its performance. Earlier in 2018, another framework is proposed by Boyes et al. [44] to design Industrial Automation and Control Systems (IACS) for Industrial IoT (IIoT) as cyber-physical systems and Industry 4.0.

2.1.6 Cybersecurity

Cybersecurity in Industry 4.0 is computer/ information technology (IT) security, which is a system that protects the computer systems and networks including hardware, software, and data of industries from any kind of inside and outside attacks/ intrusions. Industry 4.0 connects the Internet of Things (IoT) devices with industrial machines and engenders machine data so that machines can communicate with each other. In the last decade, the term cybersecurity became a very popular issue as information theft is increased a lot, and also it opened a new direction of research due to the growth of the Internet of Things (IoT) devices in industries. Cybersecurity can affect business performance with the aberration of the anomaly of networked manufacturing machines on critical industrial equipment. In 2020, Corallo et al. [45] proposed a classification model of critical assets to be protected against cyber-attacks in the context of Industry 4.0 and potential adverse impacts on business performance due to breaches of cybersecurity. In their study, the authors find the relationship between assets and impacts in terms of loss of confidentiality, integrity, and availability of data associated with networked manufacturing machines. This work supports the technical and nontechnical management staff in smart factories for decision making to confront the cyber attacks affecting the Industry 4.0. Another work published in 2020 by Lass and Gronau [46] that presented a concept to address the safety of manufacturing enterprises as a cyber-physical production system (CPPS).Implementing cyber-physical system in Industry 4.0 is critically important as well as challenging . CPS is used to control and monitor both hardware and software components in the industrial control system (ICS) in Industry 4.0 to manage industrial process control. In 2018, Radanliev et al. [41] introduced a methodology for adopting the Cyber Value at Risk (CyVaR) and the MicroMort (MM) approach to evaluate cyber risk assessment to build a new CPS in Industry 4.0. This study distinguished between IoT risk vectors and vertices for cyber risk frameworks, methods, systems, and models to cost cyber-crime. In the same year that is, in 2018, Lezzi et al. [47] published a review work based on current literature for cybersecurity in Industry 4.0 to provide the guidelines and solutions to manage cybersecurity issues within Industry 4.0. The authors discussed the types of cyber-threats and the resulting risks for industrial contexts.

Cybersecurity is the amelioration of intrusion classification, detection, and prevention systems, where the IoT, cloud computing and Big Data play the key roles. In the last decades, several works have been done to increase the performance of Intrusion Detection Systems (IDS) [48, 49, 50, 51]. IDS is a system that identifies and protects a computer system from inside and outside intruders and intrusions. In Industry 4.0, data gathering from IIoT devices and mining the data is difficult and time-consuming; the protection of data is also very important. Data storage, transferring and mining is the fundamental issue of smart factories. Data security should be guaranteed in every step from data collection to storage, and processing to knowledge mining. Industry 4.0 cybersecurity ensures security in *iIndustry* using advanced intrusion detection and prevention system, next-generation firewall, spam protection, anti-spear-phishing, vulnerability assessment, risk detection, and data leakage technologies, etc.

2.1.7 Cloud Computing

Cloud computing is the process of storing and accessing data as well as programs online over the Internet (Web); instead of personal computer's (PC's) hard drive (local storage). Cloud is essentially a metaphor for the Internet. Local storage computing means when we store data on or run programs from the PC hard drive or in a local network, e.g., storing data on a home or office network is considered as storing data in a local storage device. Nonetheless, cloud computing is the use of various services over the internet, e.g., Google Drive, Apple iCloud, Amazon Cloud Drive, Dropbox, etc. Cloud computing is generally divided into three services: (1) Infrastructure as a Service (IaaS), (2) Platform as a Service (PaaS), and (3) Software as a Service (SaaS).

With cloud computing, users can use hardware and software, access files, and applications over the Internet. Generally, cloud computing is bifurcated into public and private clouds. Public cloud is the standard cloud computing framework, which consists of files, applications, storage, and services available via the Internet, e.g., Gmail. Private cloud is composed of files, applications, storage, and services, which are stored and protected within a corporate firewall, e.g., a company using Microsoft Exchange and it can only be accessed by an authorised user through a secure virtual private network (VPN) connection. There are several advantages of using cloud computing in business like it reduces Information Technology (IT) costs, we can access data from anywhere, automatic updates of software, and scale up/down our storage needs, etc. Cloud computing has infinite storage and computational capabilities, which helps the business in all industries adapt to today's rapidly changing technology [52]. In 2019, Terrazas et al. [53] proposed a big data framework for the management and analysis of machine-generated data in the cloud. This study focuses on open-source technologies for data management to collect machine data, data pre-processing, data store, and transmission. And then a cloud-based data analysis framework is dedicated to extracting actionable knowledge from data. In 2018, Pedone and Mezga´r [54] compared two of the major frameworks for industrial Internet architectures: Industrial Internet Reference Architecture (IIRA) and the Reference Architectural Model Industry (RAMI 4.0). This study showed how both these frameworks share conceptual similarities in modeling distributed industrial services, and also how their integration feasibility finds relevant affinity in the specification of OPC Unified Architecture (OPC UA). OPC UA is a machine to a machine communication protocol for industrial automation.

2.1.8 Additive Manufacturing

Additive manufacturing is the process of joining materials to make a three-dimensional object, usually layer upon layer, as opposed to subtractive manufacturing methodologies, e.g., 3D printing. It adds material to create an object using computer-aided-design (CAD) software or 3D object scanners to build up a component in layers by depositing material. Additive manufacturing is using in many industries like aerospace, medical, transportation, energy, consumer products, etc. Additive manufacturing is needed in *iIndustry*, because it significantly reduces material waste, the number of production steps, and the number of distinct parts needed for an assembly [55, 56]. It promotes innovation in smart factories for creating new kinds of products and prototypes of any complicated parts directly from three-dimensional (3D) computer-aided design. It provides a disruptive transformation in designing and manufacturing products.

2.1.9 Augmented Reality

Augmented reality (AR) is one of the most promising technologies in the context of Industry 4.0 [57, 58]. It's a technology that superimposes a computer-generated image (CGI) of a real-world environment on a user's view, thus providing a computer-generated composite view, sometimes across multiple sensory modalities, including visual, auditory, haptic, somatosensory and olfactory [59]. It adds digital elements to a live view often by using the camera on a smartphone. Augmented reality overlays computer-generated video onto camera-captured video in such a way that the CGI objects appear to have an absolute location in the real world. In 2019, Pe rez et al. [60] presented the use of commercial gaming technologies to create a immersive environment based on virtual reality for intelligent automation and increased productivity. It also proposed the integration of safe and low-cost robot controlling capabilities in a working environment. In 2020, Masood and Egger [61] identified several issues and challenges for Industrial Augmented Reality (IAR) implementation in the age of industrial digitalisation using technology, organisation, environment (TOE) framework to facilitate collaboration and interaction between humans and production systems based on digital data. The authors proposed guidelines on which aspects the industries need to focus on to implement IAR. Another work published in 2020 by Lopik et al. [62] was focused on developing augmented reality capabilities in *iIndustry*. This study is about the development and deployment of an Augmented Repair Training Application (ARTA) for real-world Small Enterprise (SE) in the Used and Waste Electronic and Electrical Equipment sector (UEEE/WEEE).

2.2 Industry 4.0 Architecture

In this section, we discuss the Reference Architectural Model for Industry 4.0 (RAMI 4.0) and Industrial Internet Reference Architecture (IIRA) models for Industry 4.0.

2.2.1 Reference Architectural Model Industry 4.0 (RAMI 4.0)

The Reference Architectural Model for Industry 4.0 (RAMI 4.0) is a three-dimensional reference model that amalgamates all elements with IoT devices in layers and life cycle model [3, 63]. In RAMI 4.0, three axes are described as Axis 1 - Hierarchy: The Factory (the hierarchical levels of a manufacturing system networked via the cloud), Axis 2 - Product Life Cycle (the life cycle of systems and products), and Axis 3 - Architecture (the IT structure of an Industry 4.0 component) [64]. Fig. 4 shows the RAMI 4.0 model. The hierarchical system in Industry 4.0 follows the IEC 62264 and IEC 61512 standards, which include *Product* and *Internet* with Industry 3.0. The IEC 62264 is an international standard from the International Society of Automation (ANSI/ISA-95) for developing an automated interface between enterprise and control system integration, which consists of the following six parts: (1) object models and attributes of manufacturing operations, (2) object model attributes, (3) activity models of manufacturing operations management, (4) objects models attributes for manufacturing operations management integration, (5) business to manufacturing transactions, and (6) messaging service model.

The IEC 61512 standard consists of the following four parts: (1) models and terminology, (2) data structures and guidelines for languages, (3) general and site recipe models and representation, and (4) batch production records. The product life cycle in Industry 4.0 is bifurcated into Type and Instance that includes development, production/ sales, and service. The architecture in Industry 4.0 has the following six function of layers: (1) Asset Layer (physical things in the real-world), (2) Integration Layer (transition from real to the digital world), (3) Communication Layer (access to information), (4) Information Layer (necessary data), (5) Functional Layer (functions of the asset), and (6) Business Layer (organisation and business processes). RAMI 4.0 maps the key aspects of Industry 4.0. It presents and shows the entire Industry 4.0 solution that integrates Information Technology (IT) and automation technology to put them into one single model. RAMI 4.0 model establishes communication between machines and digital word (administration shell). It opens a new possibility for new business.

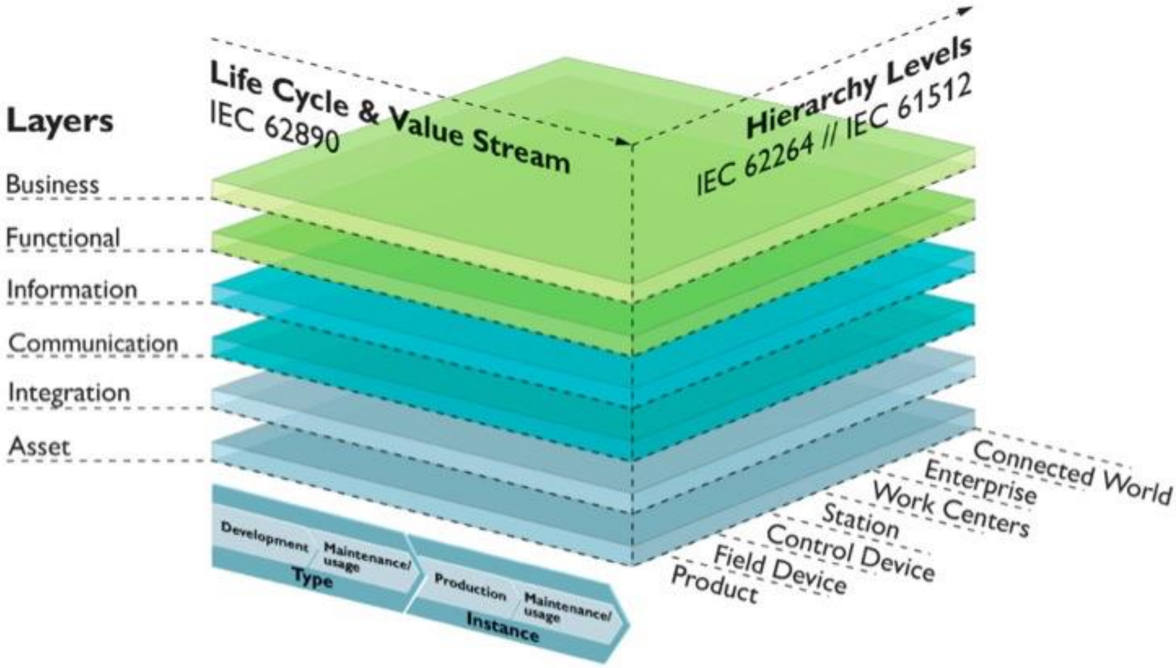

Figure 4: Reference Architectural Model for Industry 4.0 (RAMI 4.0).

2.2.2 Industrial Internet Reference Architecture (IIRA)

The Industrial Internet Reference Architecture (IIRA) is a standards-based architectural framework and concepts to design and develop the Industrial Internet of Things (IIoT) system in Industry 4.0 that shown in Fig. 5. IIRA was introduced by Industrial Internet Consortium (IIC) and its version 1.9 published in 2015 [65], which provides information for developing interoperable IIoT systems, solutions, and application architectures about wireless communications in *iIndustry* [66, 67]. It identifies and highlights important architectural concerns, concepts, and patterns for IIoT systems with four viewpoints: (1) Business, (2) Usage, (3) Functional, and (4) Implementation that adopted from ISO/IEC/IEEE 42010:2011 (http://www.iso- architecture.org/ieee-1471). IIRA provides value for IT managers and top business management for decision-making. The IIoT is one of the major technologies in Industry 4.0 that is using in all industrial sectors, such as energy, healthcare, manufacturing, public infrastructure, transportation, etc. Implementing IIoT in industries is a highly complex and challenging task because it requires a highly diverse system and architecture requirements. IIRA is an open reference architecture that encourages reuse of common and existing system building blocks to reduce project effort, risk, costs, and time-to-market. IIRA reduces operational and design cost, and enables plug & play with the IIoT system.

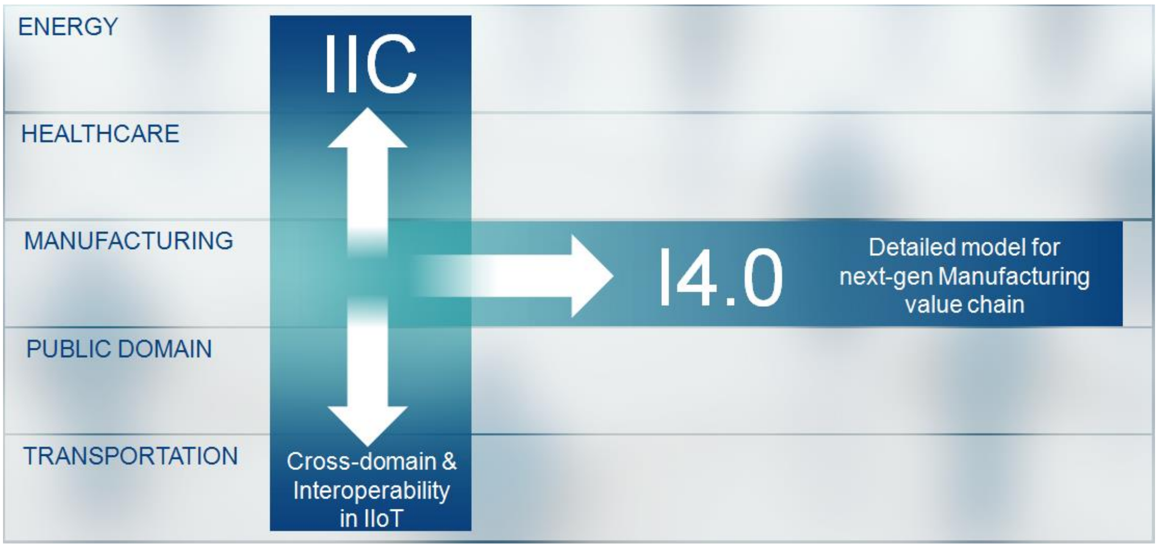

Figure 5: Industrial Internet Reference Architecture (IIRA) for Industry 4.0.

2.3 Industry 4.0 Maturity Model

Until today, a wide variety of maturity models have been developed and applied in different areas. For example, the Capability Maturity Model Integration (CMMI) is used in software engineering [68], the Business Process Orientation Maturity Model (BPOMM) [69], and the Process and Enterprise Maturity Model (PEMM) [70] in business process management.

From the perspective of Smart Industry and Industry 4.0 readiness, companies need a tool to identify their performance levels of business and production processes. Increasing complexity at all levels of a firm creates uncertainty about respective organizational and technological capabilities and adequate strategies to develop them. A maturity model is a conceptual model that comprises a sequence of discrete maturity levels for a class of processes in one or more business domains and represents an expected or typical evolutionary path for these processes. Different maturity assessment models are described in the literature.

The first maturity model, for business application, was published by Philip Crosby in 1979 [71]. He proposed the Quality Management Maturity Grid (QMMG), which is a benchmarking tool for businesses to assess the maturity of business processes concerning product quality management.

From there, the following models for assessing maturity or readiness have been published.

- **The Connected Enterprise Maturity Model** [72]: This is the technology-focused maturity model. This model assesses four domains of organization technology (OT) and information technology which are as foolows: 1) Information infrastructure, 2) Controls and devices that feed and receive data, 3) Networks that move all of the information, and 4) security policies. Rockwell also provides the five-stage approach to analyze the Industry 4.0 but does not give the details about items and development process.

- **IMPULS – Industry 4.0 Readiness** [73]: This model assesses the readiness levels of the company in 6 dimensions including 18 items. The six dimensions are 1) Strategy and organization, 2) Smart factory, 3) Smart operations, 4) Smart products, 5) Data-driven services, and 6) Employees. This model is used to measure the company's Industry 4.0 readiness level from Level 0 to Level 5. Each level contains the minimum requirements that companies should possess. An assessment survey containing 24 questions concerning related dimensions and the five-point Linkert scale are used to measure and define Industry 4.0 readiness. The barriers to progressing to the next level are defined as well as the guidelines of how to overcome them are offered.
- **Industry 4.0 / Digital Operations Self-Assessment** [74]: This is an online self-assessment maturity model. This model assesses Industry 4.0 maturity levels with six categories which are 1) Business models, products & service portfolio, 2) Market and customer access, 3) Value chain and processes, 4) IT architecture, 5) Compliance, legal, risk, security and tax, and 6) organization and culture. This model enables the company to assess the company's existing level and target level by using the five-point Linkert scale with an explanation of level 1 (minimum) and level 5 (maximum). The assessment comprises of 33 questions in total. The Industry 4.0 maturity stage is formed in four stages which are Digital novice, Vertical integrator, Horizontal collaborator, and Digital champion. The final results provide the company's Industry4.0 stage and the suggestion for the company to reach the target level.
- **The Industry 4.0 Assessment** [75]: This is a self-assessment maturity model for SMEs to assess their Industry 4.0 maturity level. The model comprises of 4 dimensions, which are operation, organization, socio-culture, and technology, 22 sub-dimensions, and 42 Industry 4.0 concepts. The described procedure has facilitated the definition of a total Industry 4.0 concepts, used as a basis for the description of the self-assessment tool. Under each Industry 4.0 concept, five maturity levels comprising the terminologies have been defined. The quantitative assessment approach consists of three components, namely the firm's score, the target level, and the importance.
- **The Smart Industry Maturity Model (SIMM)** [76] proposed by the University of Twente. It enables the company to accomplish the following:
    - Determine the extent to which the organization has implemented the processes comparing to the best practices of Smart Industry
    - Identify areas where process redesign can be made
    - Determine what technologies and methods can be utilized

- Inform external customers and suppliers of how well the organization's processes have performed compared to the best practices of Smart Industry

2.4 Industry 4.0 Business Models

A business model is a sustainable way of doing business. Here sustainability stresses the ambition to survive over time and create a successful, perhaps even profitable, entity in the long run [77]. During the early years of the new millennium the knowledge-based society along with rising globalization and the developments in the BRICS nations (Brazil, Russia, India, China, South-Africa), economies ensured that the speed of change in the business landscape has continuously accelerated. The Industrial Internet of Things (IIoT) poses large impacts on Business Models of established manufacturing companies within several industries.

Arnold, Kiel, & Voigt [78] conducted interviews in 69 manufacturing companies from the 5 most important Germany industries to analyse the influence of the IIoT on these Industries' Business Models with particular respect to differences and similarities dependent on varying industry sectors. A brief of their findings is discussed below.

- The machine and plant engineering sector experiences a considerable proportion of rising staff costs.
- The electrical engineering and ICT sectors show a great deal of importance of partner networks associated with respective coordination activities. In this context, development partnerships are perceived to play a key rolein IIoT-driven Business Models.
- The automotive suppliers represent the only industry sector experiencing comparably minor importance of the value proposition in terms of IIoT-triggered Business Model changes. The authors argue that this is related to its strong efficiency-driven nature, i.e. automotive suppliers already realized numerous potentials facilitated by the IIoT in this context.
- The medical engineering sector shows that the companies operating in this sector strongly focus on merely adapting current activities to contemporary requirements of the IIoT, hence experiencing rather slight IIoT-driven value configuration changes.

Ibarra, Ganzaraina, & Igartua [79] suggest three different approaches to make firms get closer to the industry 4.0 phenomenon:

- A Service-oriented approach: Industry 4.0 is transforming the core of the business of many companies. More specifically, Industry 4.0 is enabling the product-based companies to become service-based companies. Many researchers suggested that the manufacturing companies in developed economies should extend their products with services, resulting in a so-called product-service system (PSS) concept.

- A network-oriented approach: New ways of creating and offering value through ecosystems that go beyond individual value chains are raising. Accordingly, traditional manufacturing companies oriented to product sales, feel increasingly compelled to revise their existing Business Models in response to new competitive dynamics and to tap into those Industry 4.0 inspired opportunities.
- A user-driven approach: This context opens up inroads to make manufacturing more responsive to user-driven design since Industry 4.0 provides opportunities to create new and more flexible value propositions to respond to customer demands.

Furthermore, four different ways to innovate business models based on different degrees of innovation are proposed to embrace digitalization:

- Internal and External Process Optimization: New enabling technologies such as Big Data, Cloud Computing, Collaborative Robots, Additive Manufacturing, Artificial Vision or Augmented Reality is introduced to optimize the value creation architecture to optimize the actual business without involving big changes.
- Customer Interface Improvement: Focused on the value delivery improvement; New ways of interaction through new or improved touchpoints are created, allowing a better understanding of customers' needs and greater customer experiences.
- New Ecosystems and Value Networks: It focuses on sharing the uncertainty with other agents or achieving new required skills and resources from associates, due to the introduction of technologies such as Big Data, Cloud Computing, Augmented Reality, or Virtual Reality.
- New Business Models (Smart products and services): This proposes a completely new Business Model based on new technologies, aiming to offer innovative and smart goods and services. These new models might providean opportunity for firms to diversify or expand their markets.

3. Skills for Industry 4.0

In their journey to adopt Industry 4.0, each country is expected to encounter several challenges related to the skill level of its work force. The skills which are important today will become less important in the future, and the workforce will be expected to possess new skills in the domain of information technology, data analytics, etc. A higher percentage of the jobs will give importance to cognitive abilities and system skills over physical abilities while defining core work-related skill sets.

3.1 What skills are needed now and in the future?

The demand for special skills will drive the shift of job creation within the Industry 4.0 requiring more qualified managers. The high-tech manufacturing environment will need both skilled managerial labour and production labour with the expertise to work with new materials, machines, and especially information. Tasks will differ in the future. Skilled labour will have the opportunity to take part in greater task variety and will no longer be associated with only one particular type of job; there will be a significant reduction in monotonous and ergonomically challenging jobs. Employees will have to share space with intelligent robots. Assistant systems will support work significantly, but the final decisions have to be made by skilled employees. Information and data will be the key elements that the employees will have to process in their day-to-day jobs. Artificial intelligence will enable collaboration between humans and machines.

Industry 4.0 employs increased automated production processes and the demand for qualified employees will also increase accordingly [80]. The workforce in Industry 4.0 will perform more complex tasks and in ever-changing work environments, and the workforce will need to be upskilled and be competent in new skills to adequately participate in Industry 4.0. Reviews of both academic studies and industry reports show different categorization of the required skills for employees from different perspectives.

Grzybowska & Łupicka [81] ran a study focused on exploring the managerial competencies of future managers and engineers. Based on existing studies and analyses, a total of eight competencies were identified: Creativity, Entrepreneurial thinking, Problem solving, Conflict solving, Decision making, Analytical skills, Research skills, Efficiency orientation.

The new required skill sets will not replace the existing skill sets. Rather, these new skills will be required in addition to the skills that are important in the current scenario. Fig. 6 shows a framework for deriving skills required in Industry 4.0 [82].

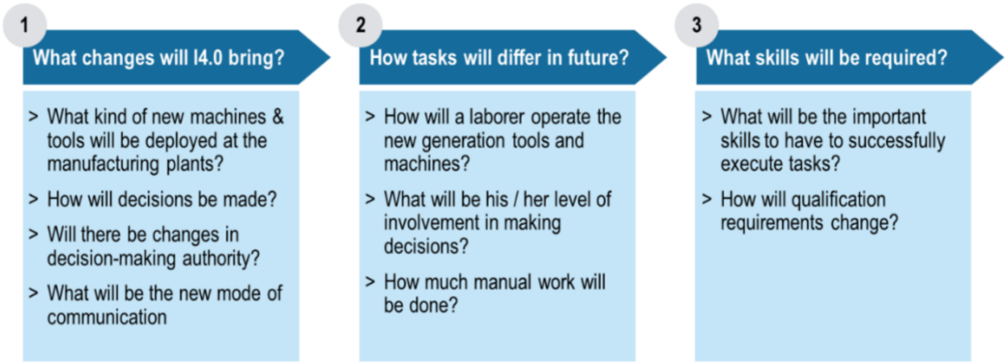

Figure 6: Framework for deriving skills required in Industry 4.0 [82].

According to a survey conducted by the World Economic Forum called 'Future of Jobs' survey, it is expected that a number of skills that are not considered to be significant in today's context will form one-third of the desired core skill sets of most occupations in 2020 [83].

Core work related skills can be classified into 3 categories and 9 sub-categories as shown in Fig. 7

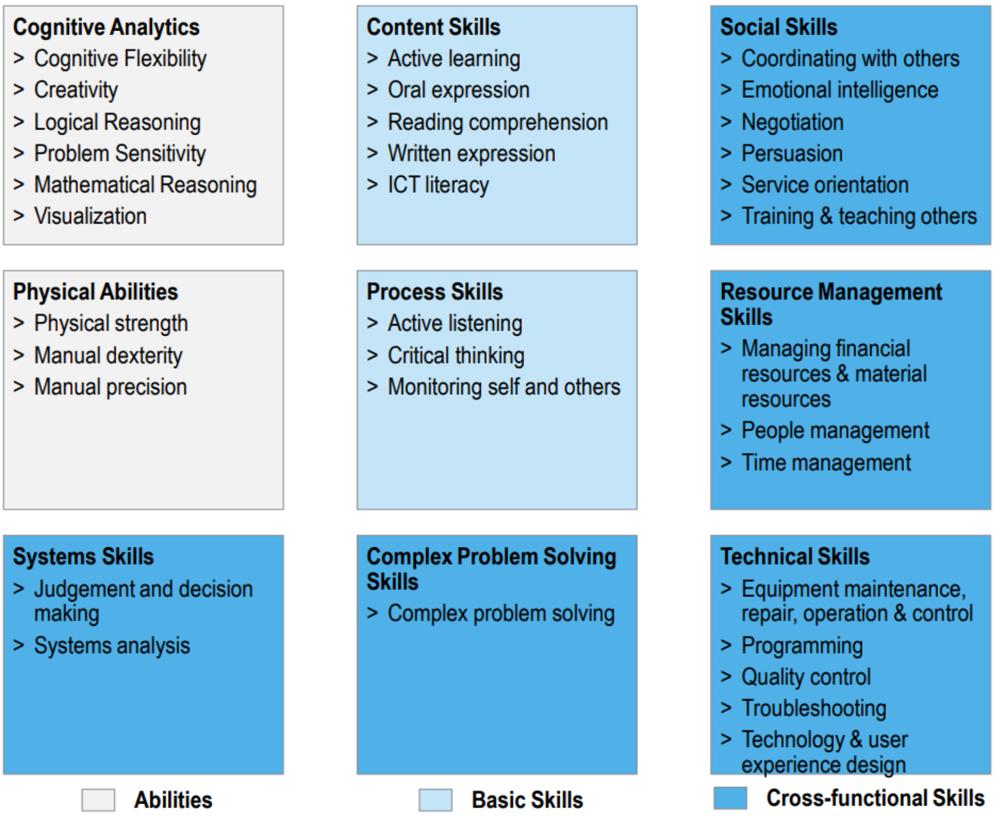

Figure 7: Categorization of skills into skill family [80].

The World Economic Forum (2016) [80] categorized three groups namely abilities, basic skills, and cross-functional skills. These three skill groups are based on 35 work-relevant skills and abilities that are widely used across all industry sectors and job families.

Another comparative study by Hecklau, Galeitzke, Flachs, & Kohl (2016) [83] focused on the competencies specific to human resource management. These researchers classified the competencies into four areas: technical, methodological, social, and personal. According to the study report by Pompa [84], the researcher proposes the framework recognizing three main sets of skills are the most important to the future success: learning and innovation skills; information, media and technology skills; and life and career skills.

Störmer, Patscha, Prendergast, Daheim, Rhisiart, Glover & Beck, H. (2014) [85] did not classify the set of skills but they pointed out that the evolution in collaborative business models and increasing project-based employment in the future need employees who have necessary business skills for example organizing, marketing, contract negotiation, and project management. However, to avoid repetition, the researchers in this study grouped and reclassified the skills that employees need to be trained in to participate in Industry 4.0 into three main skill groups; information skills, social skills, and management skills. The first group of skills is IT skills involving three parts: 1) knowledge about ICT 2) ability to work with data and 3) technical know-how that includes programming skills, media skills, technical skills, and analytical skills [80,86]. Employees need to have the ability to code in some computer languages due to the increasing use of digitized processes [84,87]. Also, they need to use smart media due to the growth of virtual work [80,83,86]. The ability to understand technical processes also cannot be ignored because many jobs and tasks in Industry 4.0 will encompass a more strategic focus moving from the operational tasks in the past [80,86,87]. Moreover, as industries rely more on information technology and digital systems, vast amount of data are created, hence, employees in Industry 4.0 will need analytical skills to manage such as inventory data of the client, customer preference and behavior, and sales tracking [80,81,85,86,87]. The second group is people management that contains two parts: 1) social skills and 2) management skills. For social skills, they are related to how employees interact and connect with each other. Social skills consist of coordinated skills/networking skills as represented by working in team and communication skills including intellectual skills. Industry 4.0 employees will need to work closely with others including their peers, suppliers, and/or customers, therefore social skills are important. Employees in Industry 4.0 will need to both coordinate and communicate with their stakeholders to retrieve data or information or to understand them [80,84,86,87].

Among businesses, there is an increased requirement for the ability to manage across networks and manage risks in volatile markets, so networking skills are significant to employees [80,85]. Industry 4.0 is also not limited to work within one country and brings down the traditional geographical boundaries, and employees will need to be culturally sensitive to understand different cultures, especially divergent work habits, when working internationally. Therefore, intercultural skills are part of the required skills that employees would need in Industry 4.0 [85,86]. Management skills include decision-making skills, problem-solving skills, conflict resolution skills, time management skills, stress management skills, speed learning skills, entrepreneurship skills, and leadership including mindset change for lifelong learning and adaptability & ability to change. In Industry 4.0, employees have increased responsibilities and will need to make more timely decisions [80,85,86,87]. Furthermore, as Industry 4.0 uses more automation, employees will need to have problem-solving skills so that they can identify the fault and solve it [80,81,85,87]. In the more complex ecosystem of Industry 4.0, there will be a higher requirement to work with others, so employees of Industry 4.0 will also need conflict resolution skills to solve any issues that can arise as a resultof group interactions [87]. Additionally, as organizations move toward a more service orientation to increase customer satisfaction, the conflict resolution skills have become increasingly more important for the Industry 4.0 employees [80,87]. As the pace of change increases in the Industry 4.0, employees will need to have the ability to manage their time or schedule to gain greater productivity and efficiency as well as to avoid losing opportunities to their competitors [80,88].

The organization structure in Industry 4.0 will also be flatter, with more employees given additional responsibilities and leadership opportunities [83,87]. As a result, leadership skills are needed by employees of Industry 4.0. Industry 4.0 is a highly competitive environment with shorter product life cycles as a result of faster product to market, and employees involved in innovation processes will require skills to cope with the associated high work pressure and stress levels [80,85]. The increased pace of change is also reflected in the roles and tasks required of the employees. Participants in Industry 4.0 will need to be “trainable”, be willing and open to on-going learning [83,88]. In this highly competitive environment of Industry 4.0, employees cannot afford to “do as they are told” but to take on a more entrepreneurial approach, taking on more responsibility and roles that are increasingly more strategic that lead to the greater improvement of their company [80,81,85,87].

To identify the skill requirements associated with career management skills, the skill categories should be clearly defined. Another point of view for skills categorization is given in Table 2. There are variations in categorization, but the main emphasis refers to core skills, transferable skills, hard skills, soft skills, meta-skills [89,90,91,92]. The term core skill is generally used by academics to denote skills that are disciplinary-specific, whereas the term transferable skill is used to denote essentially non-disciplinary skills. In addition, they found this classification to be inconsistent as skills labeled as core in one subject discipline are defined as transferable in another [90]. Transferable skills include communication skills (both input and output), interpersonal skills (working with and relating to others individually and in groups), problem-solving skills, numeracy, information technology, and in some model self-management and foreign language ability [89].

Another group categorization divides skills into three groups [91]: hard skills, soft skills, and meta-skills. Hard skills are associated with specific technical abilities or solid factual knowledge required to do a job. These skills can be termed as “what you know” [93]. The examples of hard skills for Industry 4.0 are designing, programming, CPS dispatching, etc. Soft skills can be defined as interpersonal, human, people, or behavioral skills necessary for applying technical skills and knowledge in the workplace [94] or can be termed as “how you use it” [93]. The examples of soft skills are communication, collaboration, problem identification and solving, etc. Meta-skills are involved in that kind of adaptation. It enables one to select, adapt, adjust, and apply one's other skills to different situations, across different social contexts and perhaps similarly across different cognitive domains [95].

The Partnership for 21st Century Skills (P21) proposed the 21st Century Skills model in 2002 to identify the important skills for all students in US K-12 education. The 21st Century skills comprise of 3 main areas: life and career skills, learning and innovation skills, and Information, media, and technology skills (see Table 1) [92].

Table 1: Skill Categorization

Reference	Skill category	Definition or examples
Kemp and Seagraves (1995)	Core skills	N/A
	Transferable skills	- Communication skills - Interpersonal skills - Problem-solving skills - Numeracy - Information technology - Self-management - Foreign language ability
Evans (2008)	Core skills	Skills that are disciplinary-specific
	Transferable skills	Skills that are essentially non-disciplinary
	Career management skills	A related set of meta-skills which enable individuals to develop and use the full range of their other skills
	Meta-skills	- Learning how to learn - How to select and apply skills to different contexts - Self-awareness - Self-promotion - Opportunity awareness - Matching and decision-making - Networking - Boundary management - Personal action planning
Loshkareva et al. (2018)	Hard skills	- Design - Programming - CPS dispatching - CPS maintenance - Data management - Knowledge transfer and usage - Quality control
	Soft skills	- Communication - Collaboration - Problem identification and solving
	Meta skills	- Environmental intelligence - Sustainable skills - Continuous learning - Multidisciplinary transfer - Creativity - Adaptivity
21st-century skills	Life and career skills	- Flexibility and adaptability - Initiative and self-direction - Social and cross-cultural skills - Productivity and accountability - Leadership and responsibility
	Learning and innovation skills	- Creativity and innovation - Critical thinking and problem solving - Communication and collaboration
	Information, media, and technology skills	- Information literacy - Media literacy - ICT (information, communications and technology) literacy

To define the skill requirements in a specific job domain in Industry 4.0 context, the authors of [96] deployed the skill categorization from [91] (see Fig. 8). Hard skills are technical abilities and specific knowledge of the job domain. Soft skills are interpersonal skills necessary for applying hard skills in the workplace. The necessary soft skills identification depends on the job domain and job characteristics. Thus, it is important to have a clear scope of the job domain. Meta-skills involve an adaptation of hard and soft skills to a broad set of problems. Meta-skills development takes more time than hard and soft skills development. It needs deep-learning and practice repeatedly until the subconscious knows how to do the thing. Thus, it is not an easy task to develop meta-skills for the students in higher education, but the university should provide facilities, teaching, and learning approaches that support the meta-skills development.

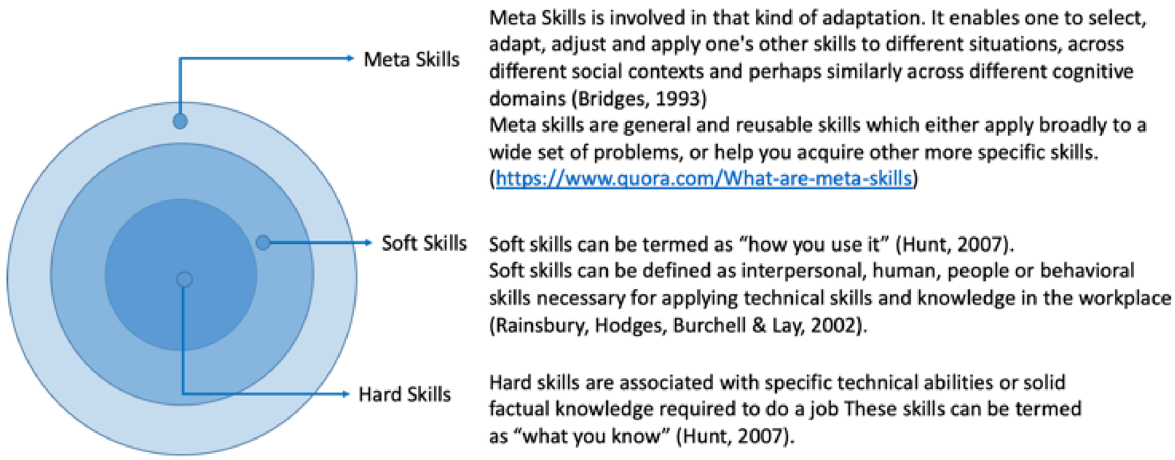

Figure 8: Skill categorization [96].

3.2 Skill development models

3.2.1 Skill development framework

The skill requirements identification in Industry 4.0 is a broad and complex issue in both academic and practical implementation. Especially, an identification which leads to design curricular and teaching & learning approach. I In [96], the authors proposed the skill development framework to design teaching and learning approach for developing the needed skills in Industry 4.0 (see Fig. 9). The proposed framework comprises of three main phases as follow:

- The first phase is the needed skills requirements identification. The job domain and related context should be clearly defined to identify the job characteristics and specific knowledge requirements. Then, the skill requirements in terms of hard skills, soft skills, and meta-skills are identified based on the literature review, survey, or in-depth-interview methods.

- The second phase is the categorization of teaching and learning approaches. The related teaching and learning approaches should be explored and categorized. The suitable approaches will be allocated to each skill requirements in the next phase.
- The third phase is designing suitable teaching and learning approaches for each skill development.

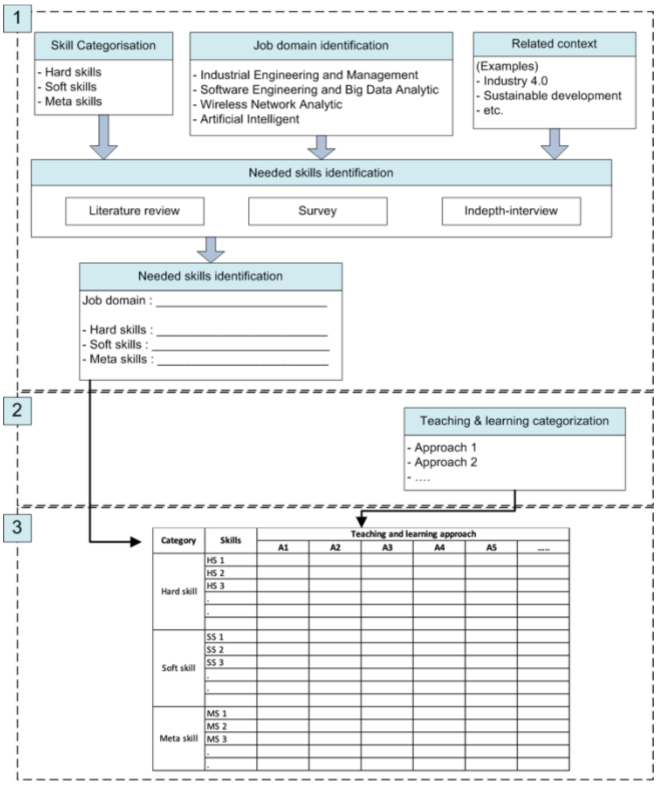

Figure 9: Skill development framework.

3.2.2 The "EU Mainboard" for digital skills

The policy paper [97] formulates two recommendations regarding the development of a European reskilling strategy. The first one is about building a "European Coalition for Reskilling and Digitizing Industry". It is intended to tie large European manufacturing companies that can help SMEs throughout the EU to develop their reskilling programs. The second one is about upgrading the network of Digital Innovation Hubs into a network for innovation and skills development and training.

More precisely, a future European mainboard for digital skills and reskilling could have the four following main components:

- Digital Skills and Jobs Coalition. Provide specific digital skills to citizens and companies
- National and regional educational ecosystems. Collaborate with local companies to develop curricula and provide training

- Digital Innovation Hubs. Already set up in some European regions; can help SMEs to understand the new production technology
- Next step. EU should bring together large manufacturing companies IoT experience and reskilling programs. The manufacturers could then accompany help companies to set up their reskilling programs in conjunction with Digital Innovation Hubs

Three kinds of added value of this Mainboard for Digital Skills Training are mentioned:

- The provision of applicable knowledge and training to IoT applications workers
- Helping European SMEs in less innovative areas to deal with the challenges of digital transformation by providing free or low-cost training for their employees
- Boosting the added value of Digital Innovation Hubs as they progress to become regional centers for skills development.

3.2.3 How CEOs shape the future of work in Asia

In their report, [98], the Economist Corporate Network (ECN) members aim to shape the future of work in Asia, by considering the three following points:

Megatrends and their impact. What are the changes driving the need for new kinds of skills in the workforce?

- More than 80% of CEOs believe the megatrends affect or strongly affect their companies. Technological progress is seen as the most important trend, with almost 60% of CEOs stating that it strongly affects their company.
- Technological progress and digitization of the economy are seen as an opportunity by close to 80% of the respondents.
- Only a small number of CEOs are confident that their company is completely prepared to deal with these trends.

Which skills are needed now and in the future? What skills are necessary and sought-after by forward-looking businesses?

- The majority of CEOs believe that most of the skills required for their business to respond to global megatrends are new skills that they neither appreciate nor use today
- 71.9% of the surveyed CEOs feel that soft skills are more important than hard skills for their business currently

- Certain hard skills such as data analytics were seen as important, but soft skills were seen as even more critical
- While hard skills can be more easily acquired and often conveyed through in-house training soft skills are much for difficult to build

Developing and acquiring the right skills? What are the challenges businesses face in "skilling up" their workforce, and what are their strategies in facing them?

- 63% of CEOs prefer a combination of *buying* and *building* talent when it comes to skills in their workforce
- One-quarter of the surveyed CEOs are unsure whether their company has the right structures in place to "skill-up" existing employees
- Only 5% of CEOs have absolute confidence in the skill training structure of their companies
- While over 60% think that they are keeping up with their peers or are even ahead of the curve, nearly 40% of the surveyed CEOs feel that their company is struggling or still at an early stage when it comes to skills management
- While more than 60% of CEOs are confident about their company's managing of future skills, slightly less than 40% are not
- 20% of CEOs still lack confidence in their ability to articulate their company's skills management strategy
- 70% of respondents agree that the shortage of suitable skills is limiting localization of management positions in their companies in Asia

3.2.4 Qualifications and Skills in the factory of the future

In [99], VDI The Association of German Engineers and ASME American Society of Mechanical Engineers joined efforts to study the impact of industrial innovation on the role of humans in the future of manufacturing.

The four following objectives are targeted:

- Introduce the matter of the fourth industrial revolution
- Describe the effects of this revolution on the skilled labor
- Derive qualifications and skills that will become more important for the workforce
- Recommend ways and measures to qualify the workforce for the future against the background of the educational systems of the USA and Germany

Hereafter, we focus on the two last points and we report the findings.

Important qualifications and skills

From the analysis of Industry 4.0 future tasks, a list of different qualifications and skills, have been generated. Those qualifications and skills differ with respect to importance. They are classified as “Must”, “Should”, “Could” be included in the skillset of the skilled labor of the future, as shown in Table 2.

Measures to qualify the workforce - Recommendations

Measures of qualifications are presented in Table 3. They are evaluated towards the identified technical and personal qualifications and skills. The evaluation ranges from “well-suited” to “not-suited”. A “well-suited” measure is capable of delivering a certain qualification or skill very effectively. A “suited” measure does so in a moderately effective way. A “not-suited” measure is not useful to deliver a respective qualification or skill.

Table 2: Qualifications and skills of workers in a factory of the future [99].

	Must…	**Should…**	**Could…**
	…be included in the skillset of the skilled labor of the future.		
Technical Q&S	IT knowledge and abilities	Knowledge Management	Computer programming/coding abilities
	Data and information processing and analytics	Interdisciplinary / generic knowledge about technologies and organizations	Specialized knowledge about technologies
	Statistical knowledge	Specialized knowledge of manufacturing activities and processes	Awareness for ergonomics
	Organizational and processual understanding	Awareness for IT security and data protection	Understanding of legal affairs
	Ability to interact with modern interfaces (human-machine / human-robot)		
Personal Q&S	Self- and time management	Trust in new technologies	
	Adaptability and ability to change	Mindset for continuous improvement and lifelong learning	
	Team working abilities		
	Social skills		
	Communication skills		

Table 3: Evaluation of measures for the qualification of skilled labour [99].

		Technical Q&S													Personal Q&S							Eval.
		IT knowledge and abilities	Data and information processing and analytics	Statistical knowledge	Organizational and processual understanding	Ability to interact with modern interfaces	Knowledge Management	Interdisciplinary / generic understanding	Specialized knowledge	Awareness for IT security and data protection	Computer programming/coding abilities	Specialized knowledge about technologies	Awareness for ergonomics	Understanding of legal affairs	Self- and time management	Adaptability and ability to change	Team working abilities	Social skills	Communication skills	Trust in new technologies	Mindset for improvement	++ = Very Effective (>70% of max. effectiveness) + = Effective (>50% of max. effectiveness)
Early education	Mandatory school subjects	●	●	●	○	○	○	○	●	○	●	○	○	○						○	○	+
	School Internships		○		●	●	○	●	●	○	○	○	○	○	○	○	○	○	○	○	●	+
	Summer school initiatives	○	○	○	○	●	○	○	○	○	○	○	○	○	○		○	○	○	●	○	+
	Open day tours				○			○		○			○							●	●	
Transition from School to Work	2Yr. 'light' manufacturing degree	●	●	●	●	●	●	○	●	○	●	●	○	○	○	○	○	○	○	●	○	++
	Engineering mentoring program	○			○	○	○	○	○	○		○	○	○	○	○	○	●	●	○	●	
	Workshops	●	●	●	○	●	○	○	●	●	●	●	●	●	○	○	○	○	○	○	○	++
	Internships	○	○	○	●	●	○	●	●	○	○	●	●	○	○	○	●	○	○	○	○	+
	Professional Development Courses	●	●	●	○	●	○	○	●	●	●	●	●	●	○	○	○	○	○	○	○	++
	MOOC	●	●	●	○	○	○	○	●	○	○	●	○	●	○					○	○	
	Open day tours				○	○		○		○			○							●	●	
	University/industry collaboration	○	○	○	●	●	●	●	●	●	●	●	○	○	○	○	○	○	○	●	●	++
Continuous Vocational Training	MOOC	○	●	○	●	○	○	●	●	○	○	●	○	●	○	○			○	○		+
	Workshops	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	○	●	●	○	○	++
	Open day tours				●			○		○			○							●	●	
	Industry/university collaboration	●	●	●	○	●	○	○	●	○	○	●	○	○	○	○	○	○	○	●	●	+
	Department presentations				●		○	●	○	○			○	○	○	○	○	○	○	●	●	
	Professional Development Courses	●	●	●	○	●	●	○	●	○	●	●	●	●	○	○	●	○	●	○	○	++

● well-suited ○ suited - not suited

3.3 Adopting Industry 4.0

In most developing nations, there exists a mismatch between the skill sets job applicants have and the skill sets they are expected to possess. In the scenario where Industry 4.0 technologies have been widely adopted, this demand-supply gap will widen even further if necessary actions are not taken by each country. Some experts have opined that people in countries who are new to the industrial sector are confused and are facing structural challenges over the term Industry 4.0; therefore, it has taken time to apply and adopt the elements of Industry 4.0 and to gain the benefits of this [100-105]. A study has been conducted by the researchers from the University of Putra, Malaysia to determine the readiness for Industry 4.0 in Bangladesh [106], which has been recognized as one of the fastest-growing economies in South Asia. This study found that lack of knowledge is one of the 5 main challenges that the country is facing. These 5 challenges are:

- Poor infrastructure

- Availability of cheaper labour
- Expensive installation of technologies
- Lack of government supports
- Lack of knowledge

Arison Tamfu [107] states that unemployment remains a major challenge in developing countries, and new technologies will simply compound the situation. Driverless trucks, cabs, and robots will mean the loss of thousands of jobs in a single city like Nairobi and the social effects will be devastating.

The BRICS nations offer a case of special interest since they currently account for nearly a quarter of the world economy and contributed more than half of global economic growth in 2016 (BRICS is of great importance to emerging economies: experts, 2017). Though the governments of the BRICS nations have undertaken independent initiatives to promote vocational education and skill development in their countries, there are still significant efforts required for focusing on skill development for Industry 4.0 [82]. In [82], the authors studied the performance of BRICS nations in the education space, to understand the current skilling levels. The attributes studied are depicted in Fig 10, 11, 12, and 13.

In Fig. 10, we observe that at secondary education level, the enrolment ratio of the BRICS nations is close to 95% except for India where the ratio is 69% that is sigficantly lower than the others. The main reason for low participation in India is the high percentage of students leave school after the completion of the primary level of education to join the workforce.

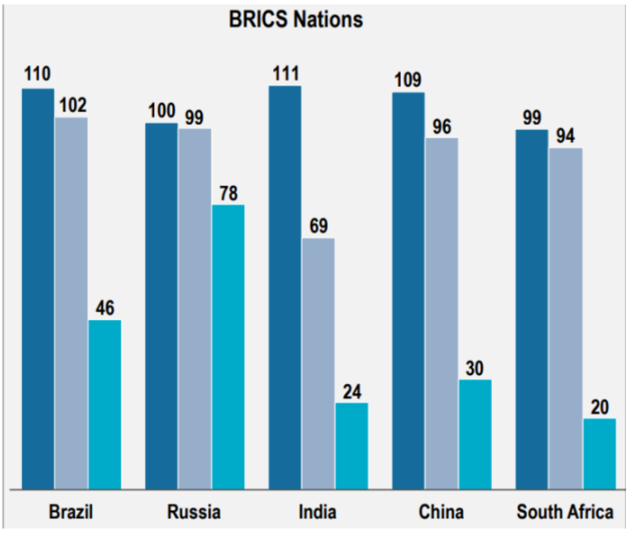

Figure 10: Gross Enrolment Ratio at various education levels, in percentage, 2013 [82].

Note: Gross Enrolment Ratio = No. of actual students enrolled / Number of potential students; this also includes the grade repetition and hence it can be more than 100%

In most of the BRICS nations, vocational education is introduced at the secondary education level. In Fig. 11, we observe that all BRICS nations, except for Russia, have a lower gross enrolment ratio at the upper-secondary education level. India has the lowest enrolment ratio of 56% at upper-secondary education level amongst the BRICS Nations, almost in line with its low secondary level enrolment.

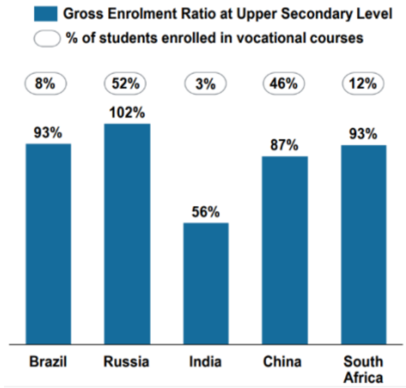

Figure 11: Gross Enrolment Ratio at Upper Secondary Level, in percentage, 2013 [82].

In Fig. 12, we can see that in terms of the basic ability to read and write, BRICS nations, except for India, have a high literacy rate amongst the people with more than 15 years of age and can be considered to have reached universal literacy to a great extent.

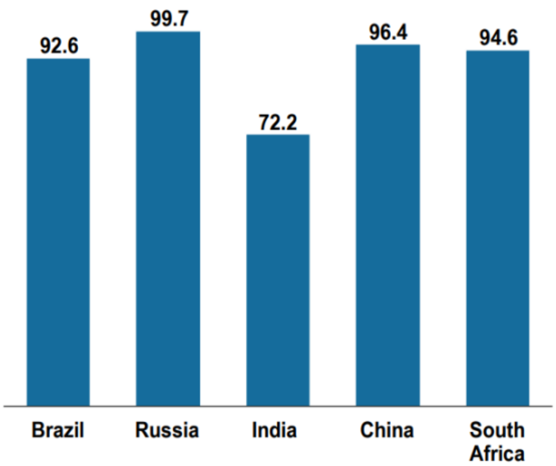

Figure 12: Literacy Rate amongst people with 15+ years of age, in percentage, 2015 [82].

By law, all the BRICS nations require students to mandatorily attend at least 9 years (8 years for India) of education. In Fig. 13, we observe that the average number of years of education received by students in Brazil, India, and China is 7.2 years, 4.4 years, and 7.5 years respectively while South Africa has 9.9 years of education on average. Russia, on the other hand, is the only country amongst the BRICS nations which has mean years of education of 11.5 years, comparable to 11 to 12 years in other developed nations.

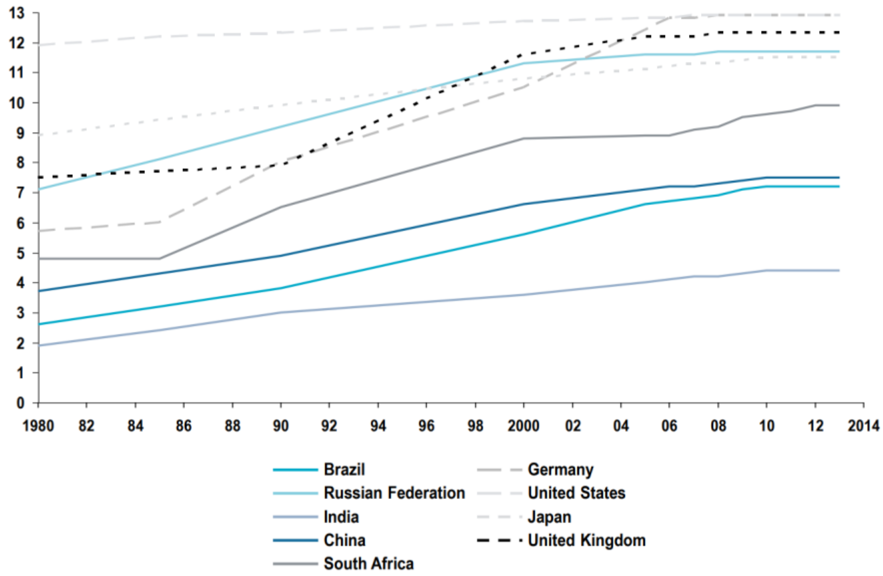

Figure 13: Mean years of education received by people above 25 years of age [82].

In Europe, the countries are facing a number of challenges today. An unacceptably high proportion of Europeans – one in five – are still having difficulties in reading and writing. Many in Europe cannot find a job because they do not have the right skills or they are working in jobs that do not match their talents, and at the same time, 40% of employers cannot find people with the right skills to fill their vacancies [108].

Education and training in Europe are the competence of Member States. That is why European initiatives for skills aim to mobilize all European stakeholders along the following lines of action:

- Understanding skills:
  - EQF: The European Qualifications Framework [109] aims at making qualifications more transparent and comparable and so portable across borders – to help workers, learners, and employers.
  - Skills intelligence: The EU Skills Panorama [110] is an online tool providing central access to data, information, and intelligence on skill needs in occupations, sectors, and countries.
  - Sectoral forecasting and skills development: This can be an effective way of anticipating and meeting needs in different sectors through setting out specific measures to satisfy short and medium-term skills needs, and tackling skills gaps by identifying needs for one or more occupational profiles, and making vocational systems more responsive.
- Developing skills: Entrepreneurship Competence Framework (EntreComp) [111] is a tool to support a common understanding of entrepreneurship competence and to enable people to develop entrepreneurial competencies to support their life chances and employability.

- Showing Skills: Quality Assurance arrangements and principles are put in place to ensure high quality and relevant education and training systems and delivery. All types and levels of qualifications that are referenced to the EQF should be quality assured to enhance trust and confidence in the quality of education.

Country specific recommendations related to skills development are addressed to a high number of Member States each year to guide their national policymaking.

In the United States, many workers are already engaged in an ongoing effort to improve their skills or learn new ones. 45% of employed adults responded that, in the past 12 months, they have taken a class or received extra training to learn, maintain, or improve job skills. Workers younger than 50 are somewhat more likely than the ones whose age is 50 and older to say that they have sought out this type of training (47% vs. 39%) (Fig. 14) [112].

Figure 14: Reasons why US workers have, in the past year, taken a class or gotten training [112].

While most workers expect training and skills development to be an integral part of their working life in the future, and many are taking classes and getting certifications in realtime, about one third (35%) of the workers in the US responded thatthey lack the education and training necessary to improve the position in their current job; 64% of employed adults responded that they received the education and training needed for promotion in their current jobs (Fig. 15) [112].

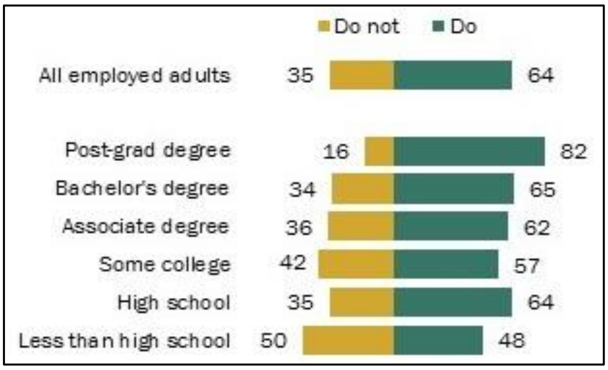

Figure 15: % of US employees saying they have the necessary education/training to get promoted in their current job [112].

4. Development of new learning materials focusing on IR 4.0

4.1 Teaching and Learning Strategies

Teaching and learning is the process of gaining new knowledge and skills in a subject or activity that synthesise new understanding from prior learning and new information. It's the process of sharing and transferring knowledge by constructing new ideas and concepts, which helps us to transform knowledge, construct hypothesis and decision making etc. Basically, learning is the process of study and repeat something in order to be able to remember it, e.g. a poem. In this following section, we will discuss the following seven modes of effective teaching and learning strategies: (1) Lectures, (2) Massive Open Online Courses (MOOCs), (3) Flipped Classroom, (4) Active Learning, (5) Blended Learning, (6) Problem-Based Learning and (7) Work-Based Learning.

Lectures - Courses

The traditional form of teaching in the tertiary-level education often involves lectures being given to a group of students by an academic. A lecture basically an oral presentation to teach students about a particular subject, which is a common teaching method in academia. Lectures are the most impactful, effective and engaging way to promote student learning. Lectures also allow students to ameliorate their interactive and collaborative skills that is difficult to develop in self-study situations. It also helps students to understand the development of the argument/ideas by active participation, and lead to a bigger interest and motivation into the subject/course.

Massive Open Online Courses (MOOCs)

A massive open online course (MOOC) is the process of providing open access (free and open registration) online learning content/course aimed at unlimited interactive participation employing the web, e.g., OpenCourseWare (OCW) by MIT (Massachusetts Institute of Technology). MOOCs provide interactive user forums to build communities for students/learners and academicians using online resources and social networking. Most significantly, MOOCs are very useful for distance education by accessing free educational resources, e.g., lecture notes, videos etc. MOOCs are new pathway in higher education for connecting people to share their learning experiences, because anyone can participate the courses from anywhere in the world, e.g., Coursera (https://www.coursera.org).

Flipped Classroom

The flipped classroom is a pedagogical model, which is type of blended learning where lectures (e.g., video lectures) are introduced/viewed by the students at home before coming to the lecture. The video lectures are one of the important elements in the flipped approach that are developed by the academician and provided to students prior to the lecture. In lecture time, students can discuss and inquire about the lecture content, test their skills by applying knowledge, and do some practical activities. Generally, students watch online lectures, collaborate in online discussions using social media, do some homework and do some activities in the classroom with the guidance of a mentor in a flipped classroom.

Active Learning

Active learning is a learning and teaching method to help students and instructors into effective ways to help everyone engage in meaningful activities based on the concepts about how people learn in a deliberate contrast to passive learning. In active learning, students are actively involved in the learning process and must engage in higher-order thinking, i.e., analysis, synthesis and evaluation. It has two aspects – doing things and thinking about the things students are doing.

Blended Learning

Blended learning also known as hybrid learning, is an approach to education that amalgamates online learning with face-to-face teaching (i.e., traditional classroom teaching), allowing the students to have more control over time, place, path/pace and style of learning. Blended learning amalgamates the strengths of both traditional and online learning methods in order to ameliorate learning experience. Webinars can be a useful tool for blended learning, e.g., Zoom, GoToWebinar, Cisco WebEx, Adobe Connect, Google Hangouts, AnyMeeting etc.

Problem-Based Learning (PBL)

Problem-based learning (PBL) is a learning by doing teaching method in which complex and authentic real-world problems are solved by the students that helps to develop critical thinking skills, problem-solving abilities, reasoning, communication and self-assessment skills. PBL also provide the opportunities to work in groups (i.e., students work with classmates), finding and evaluating research materials and life-long learning. PBL commonly use in medical education where students learn dealing with real-life medical problems, however this technique can be used in other fields, e.g., education, business, engineering, law, architecture, music and literature etc.

Work-Based Learning (WBL)

Work-based learning (WBL) is an educational strategy that places students both in the classroom and real-life work experiences (i.e., the workplace) to prepare students for real-world careers. WBL integrates the educational institute curriculum with the workplace to create a different learning paradigm that could be done by doing internships, job shadowing or field trips. WBL helps to students to apply academic and technical skills in terms of professional development.

4.2 Education Towards Industry 4.0

In this section, we present some recent teaching and learning trends that can be suitable to deliver knowledge related to Industry 4.0: Education 4.0, new teaching methods and learning process, the Teaching Factory.

The technology-based teaching and learning method is known as Education 4.0, which is inspired by Industry 4.0. Education 4.0 aims to improve the digital technological competencies across all levels and enhance the use of digital technologies for teaching and learning. The approach functions in four ways: basic digital education for all pupils and students, digitally competent educators, learners and employees, and digital educational media. Education 4.0 enables the students to adopt real-world skills that are representative of their jobs. We are on the cusp of this new type of education. For Education 4.0 to be effectively adopted, HEIs' curricula need to be designed in an effective way so that it creates more opportunities for students to fulfill internships, monitoring projects, and work on project-based activities (Learning by Doing). Education 4.0 underlies unconventional but effective methodologies that would change the traditional ways ofevaluating students . Students are not examined to assess their ability in memorizing educational materials; instead, they are evaluated in real-time according to their performance while working in real-life projects . These approaches do not only ensure technical competencies of the students but also make them eligible to bethe employees of the companies adopted Industry 4.0 [113].

The study of Hariharasudan & Kot in [113] has identified three results (gaps) after an analysis of previously conducted studies related to the fields of Digital English, Education 4.0, and Industry 4.0.

- There is a vibrant interconnection between Digital English and Education 4.0 and both are mutually interdependent and adopted in many countries to augment individual and institutional growth. Thus, Digital English and Education 4.0 are interlinked in many places. However, the study also suggests researching the application of Education 4.0 in other subjects too.
- It is identified that the Digital English is in the wish list of Internet of Things (IoT) users and most IoT operations are developed by English only. Digital English is a medium of IoT in both levels as a programming language and instructive language. However, no such research has been conducted by analyzing the impacts and importance of Digital English in IoT or any other Industry 4.0 operation.
- The study conducted by Slusarczyk [114] reveals that lack of training or knowledge' is one of the key challenges of Industry 4.0. In the study, almost half of the respondents have indicated that there is a lack of training or knowledge in Africa and lack of properly qualified staff in Germany. One of the suggestions by Wallner [115] reveals that in future, the industries will be fully automated. If the students need to cope up with Industry 4.0 ecosystem, they have to adopt the prerequisites that can be achieved through Education 4.0. From the studies, it is evident that Education 4.0 is the most promising

approach to build a generation of experts who could serve the companies in the era of the fourth industrial revolution. To the best of our knowledge no research has been carried out by analyzing the impacts and importance of Education 4.0 for Industry 4.0.

Dunwill [116] discloses that the advancement of technologies keeps on changing and transforming the teaching method and the setting of the learning process. He predicted how an average classroom will look like in the next 5 to 7 years.

- A huge change in the layout of the classroom
- Virtual and augmented reality will change the educational landscape
- Flexible assignments will accommodate multiple learning styles
- MOOC and other online learning options will impact secondary education

A similar transformation has already taken place in tertiary education. Student assignments are no longer in the form of constructed or selected responses only. In addition, tertiary education has started using Massive Open Online Courses (MOOCs) and other online learning platforms in teaching and learning.

The authors of [117] present a study aiming at upgrading traditional manufacturing courses to a Teaching Factory 4.0. The Teaching Factory paradigms aims to involve aspiring engineers in an environment in close collaboration with experts on the field so as to familiarize them with its requirements and enhance the collaboration between involved parties with different knowledge and background. The architecture of the transformation of a teaching factory towards a Teaching Factory 4.0 paradigm is depicted in Fig. 16.

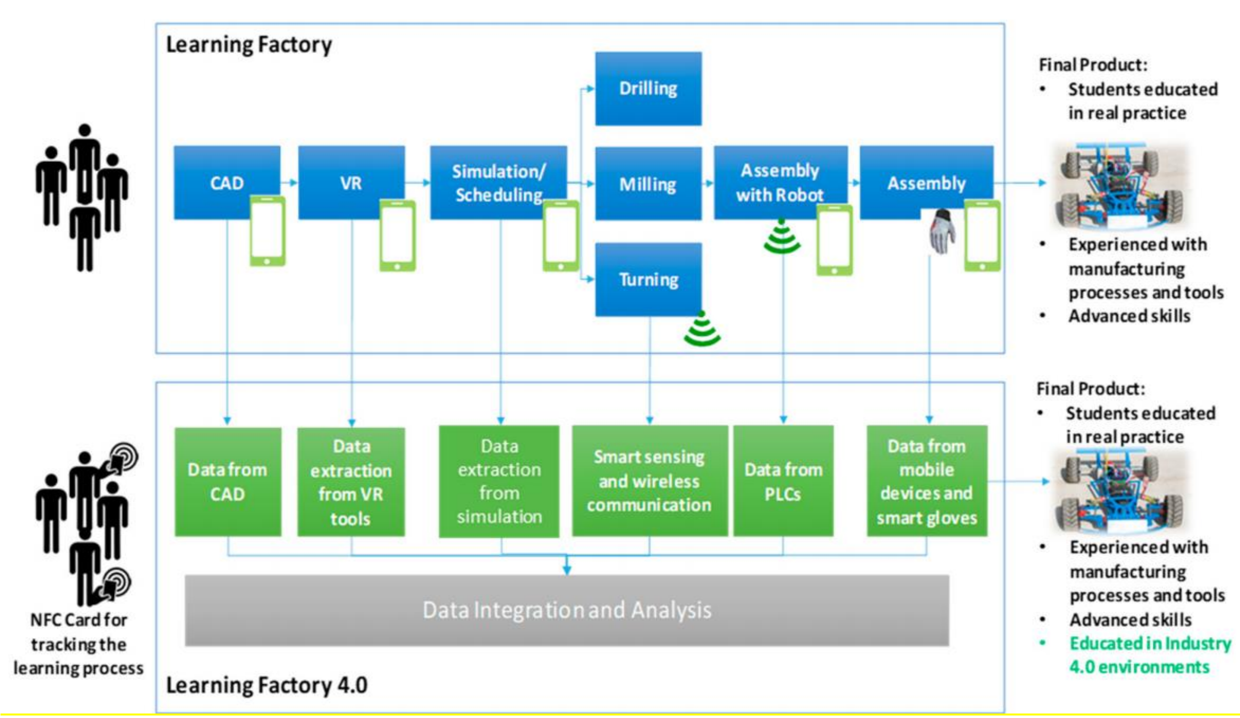

Figure 16: Architecture of the proposed Teaching Factory [117].

The goal of the Teaching Factory 4.0 is the design and manufacturing of a radio-controlled electric car. The participants, separated in groups, are given the initial requirements of the final solution, some specifications that need to be met, a set of standardized parts that need to be included in their designs, and the available resources for manufacturing it.

4.3 Preparing Students and Learners for Industry 4.0

Hereafter, we identified some trends in the literature intended to prepare students and learners to face up Industry 4.0.

On the needs of new learning and teaching methods

According to [118], further qualification and skills of human capital for Industry 4.0 can be divide into personal and technical skills hence need a revolution in teaching and learning methods. It is important to note that Industry 4.0 is not only about the advancement in technology, but also about the advancement in the learning process especially at the tertiary level to provide a skillful human capital to drive the development of the fourth industrial revolution. Higher Technical and Vocational Education and Training (HTVET) is part of the education platform in producing skillful human capital.

About Technical and Vocational Education and Training

Consider Malaysia as a case to illustrate how Technical and Vocational Education and Training (TVET) is apprehended in higher education. It appears that TVET is still being seen as a second-class choice for HEI students, especially compared to pure science and engineering courses. The authors in [119] highlighted some suggestions on the gaps that need to be addressed in TVET teaching and training to adopt Industry 4.0 in Malaysia:

- Training institutions should re-evaluate their course content to make it more up-to-date
- Modeling and simulation-based laboratories have to be established to enhance students' programming skills
- Curriculums of technical and vocational school need to be re-audited so that they can keep pace with the rapidly changing industry
- Increase competency of the teachers by providing training to deliver quality technical education and to increase TVET facilities and infrastructure
- Evolving certification and accreditation systems based on agreed industry standards and the identified needs
- Improve the social status of TVET as a viable education pathway among learners, families, employers, policymakers and other stakeholders

- Policymakers, investors, and politicians should balance more evenly between academic and TVET education reform and funding
- Funding and investments from both government and industry to the HEIs in developing TVET and Industry 4.0-related courses.

Engineering Education 4.0 Program

Teaching program based on Competencies and Learning Blocks

Other than that,In [120], the authors proposed the Engineering Education competency-based curriculum framework. Some general competencies are identified and presented in Table 4 in the paper. Some topics are proposed and organized through knowledge modules. These modules are Industrial Automation and Control, Production, Business, and Management Principles, Advanced Manufacturing and Information and Communication Technologies. Fig. 17 shows an innovative way to organize a semester based on a logic structure called a block. Fig. 18 shows the strategy of Teaching-Learning for Engineering Education 4.0, it is inspiredby the Swiss Smart Factory.

Teaching and Learning methodologies

The curriculum of Engineering Education 4.0 program at the undergraduate level consists of the design of a challenging experience each term of the program, where the students are involved in a complete immersion in a real learning environment. This design employs a combination of Active Learning techniques, like Problem Based Learning and Problem-Oriented Learning, where the learning process occurs in a way that is connected to a reality based on the resolution of a concrete project. Blended learning is inspired by the correct combination of face to face class sessions with extra support material which may be online. Personalization of learning can also be a differentiating element of the blended learning methodology with a combination of learning spaces. Assessment is based on competencies and is a key feedback step into this teaching-learning process. The structure of the curriculum details out the competencies, soft skills, and outcomes required. Flexibility in competency development based on real challenges will be established.

Macro-organization

Tecnológico de Monterrey (Instituto Tecnológico y de Estudios Superiores de Monterrey, ITESM, South America) has designed a research-action model: Research that Transforms Lives. This model is based on a collaborative, interdisciplinary, and open innovation ecosystem that involves faculty and researchers as well as students. Several strategic research groups have been created to support the Engineering Education 4.0 Program. Their scientific activity is centred on specific challenges related to their disciplines. The research groups represent a key element in the Engineering Education 4.0 Program because they areresponsible for inviting students in the research projects.

Table 4. General Competencies for Engineer 4.0 [120].

Competencies (general skills)	**Description**
Virtual Collaboration	Virtual collaboration tools offer great value for improving communication. New virtual social networks are being developed by companies such as Facebook or Google. These tools allow organizations to take advantage of the knowledge of all their members enabling them to interact more efficiently and rapidly, regardless of the distance or physical location of each member [121,122].
Resilience	Defined as the proficiency to overcome diverse backstrokes, dares, and challenges. The development of this skill is relevant for either individual and organizational level [123].
Social Intelligence	Social intelligence, or empathy, is the ability of a person to relate to others effectively and peacefully. To do this, verbal and emotional intelligence, listening, paying attention, and managing physical contact are used [123].
Novel and adaptive thinking	Skills that facilitate quick and adaptive responses to outside circumstances will be awarded in the changing world of increasing global connectivity, market competition, and automation. It is expected that as everything gets connected thanks to new technologies, the whole system will become unpredictable and incredibly complex. Adaptive thinking will help engineers to overcome such complexity [122].
Load cognition management	The world is creating a vast amount of data every second. Data are stemming from a wide range of sources such as people, objects, processes. To be able to manage massive scale data and obtain useful insights from these data foster a huge obstacle which is a relevant tool for new generation engineers [124,125].
Sensemaking	Smarter machines and devices are being currently developed. Those machines and devices are designed to carry out advanced tasks. Hence, engineers must skill up in competence accordingly.

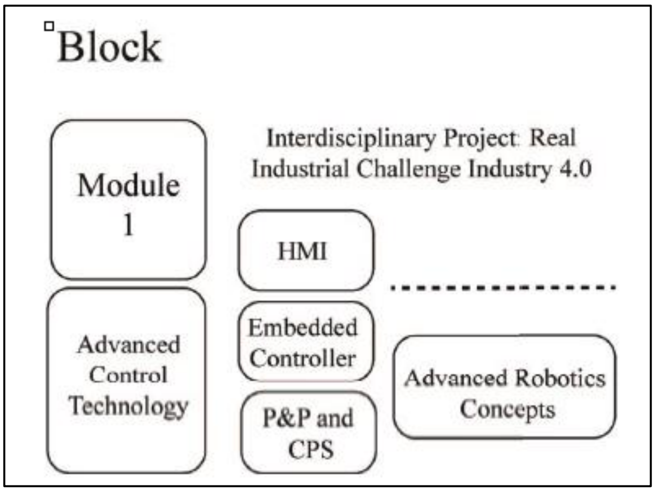

Figure 17: Typical Organization of a Pedagogical Block [120].

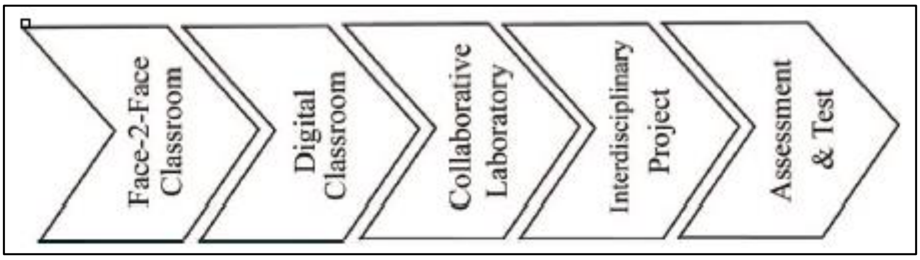

Figure 18: Teaching-Learning Model [120].

The proposition of 6 Blocks of knowledge derived from a professional interview

In [126], the author states that a logical, systematic, and progressive approach to teaching the complex topics underlying Industry 4.0 is of critical importance. He identifies 6 “Education Building Blocks” summarizing Industry 4.0 that must be delivered in an appropriate complexity depending on the level of education. Those blocks are as follow (1) Industrial Success Skills (Related to the understanding of the disciplines that underpin industrial success) (2) Industrial Equipment and Technology (Related to the understanding of the production and manufacturing equipment that underlie Industry 4.0) (3) Smart Sensors and Smart Devices (Gathers volumes of information about its environment and then uses embedded intelligence to execute programmed functions and share the information with other systems and devices) (4) Control Systems (Systems controlling the entire manufacturing process at real-time) (5) Connectivity and Networking (specifically related to the increasing use of Internet Protocol in Industry 4.0 and the related issues) (6) Inform-Actionable© Data (related to performing analysis, drawing conclusions and taking actions, from data).

The authors of [127] emphasized that learning in the context of Education 4.0 can be taken place anytime anywhere thanks to e-learning tools which offer opportunities for remote and self paced learning. Learning is personalised and students can choose how they want to learn and they are exposed to p-based learning which is focused on hands-on learning activities. In [128], the authors concluded that learning takes place in a more active and project-based settings. Students are empowered in their learning and assessments can be individualized. Furthermore, the authors stressed the importance of liberal arts-type education with modifications to adapt to the particular issues raised by 4IR technologies and their disruptions to society.

5. Conclusion

We reviewd in this report the literature related to the latest concepts, models, and infrastructures for manufacturing in the revolutionary Industry 4.0 for a comprehensive understanding of the challenges, approaches, and used techniques in this domain.

After a description of the context and the evolution of the industry in the last decaces, the main technologies and models related to the industry 4.0 are defined. Nine technologies to transform the industrial production for changing traditional production relationships between suppliers, producers and customers are discussed: IoT, Bigdata, Simulation, AI…

An analysis of the maturity models for industry is presented. Indeed, from the perspective of Smart Industry and Industry 4.0 readiness, companies need a tool to identify their performance levels of business and production processes. Different maturity assessment models are described in this deliverable.

In the second part of the deliverable, we focused on the challenges related to the skill for the industry. The skills which are important today will become less important in the future, a higher percentage of the jobs will give importance to cognitive abilities and system skills over physical abilities while defining core work-related skill sets. In this section we tried to answer the question "What skills are needed now and in the future?" by looking at skills development models and frameworks, such as the EU Mainboard for digital skills, "CEOs shaping the future of work in Asia", "Skills and competences in the factory of the future"... and concluded on how best to embrace Industry 4.0.

The last part of the deliverable concerns the development of new learning materials focusing on industry of the future. We have devided the analysis in three main dimensions:

1. the teaching and leairning strategies: we discussed seven modes of effective teaching and learning strategies: (1) Lectures, (2) Massive Open Online Courses (MOOCs), (3) Flipped Classroom, (4) Active Learning, (5) Blended Learning, (6) Problem-Based Learning and (7) Work-Based Learning.
2. Education Towards Industry 4.0: In this section, we presented some recent teaching and learning trends that can be suitable to deliver knowledge related to Industry 4.0: Education 4.0, new teaching methods and learning process, and the Teaching Factory.
3. Preparing Students and Learners for Industry 4.0: we identified in this section some trends in the literature intended to prepare students and learners to face up Industry 4.0.

We can conclude that Industrial production is nowadays driven by global competition and the need for fast adaptation of production to the ever-changing market requests. Industry 4.0 seems to be a promising solution that could revolutionize the current industrial ecosystem, and push development to the next level.

This radical advancement is mainly due to technologies underlying Industry 4.0. Due to the recent advancement of Information and Communication Technology (ICT), Machine-to-Machine (M2M) communication, and Wireless Sensor Network (WSN), new technologies such as Cyber-Physical Systems (CPS), Internet of Things (IoT), and Internet of Services (IoS) are emerging to achieve effective automation and connected world.

These Industry 4.0 technologies will have a significant impact on building the industries of the future. Companies wishing to make a transition to the digitally integrated production model proposed by Industry 4.0 must evolve their skills and adapt their strategies to implement them.

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