Development of Skills and Competences in Manufacturing Towards Education 4.0: A Teaching Factory Approach

Dimitris Mourtzis(✉)

Laboratory for Manufacturing Systems and Automation,
Department of Mechanical Engineering and Aeronautics, University of Patras, Patras, Greece
mourtzis@lms.mech.upatras.gr

Abstract. Industry 4.0 manufacturing paradigm, apart from the technological revolution requires also a shift from the traditional education to an advanced set of methods for developing skills and building digital competences, summarized in the term Education 4.0. Human skills undoubtedly require upgrading to handle the key enabling technologies sufficiently, including machines as cyber-physical systems, augmented reality, human-robot collaboration, and smart devices. In the present work, these new requirements for the enhanced manufacturing workflow are presented. Furthermore, existing education 4.0 approaches are investigated, and finally, a Teaching Factory concept adapted to the Industry 4.0 paradigm needs is proposed.

Keywords: Manufacturing · Industry 4.0 · Education 4.0 · Teaching factory

1 Introduction

Due to the recent advancements in information technology (IT), manufacturing research has entered a new era of product planning, analysis and troubleshooting, moving forward to the Industry 4.0 paradigm [1]. Digital manufacturing has been considered, over the last decade, as a highly promising set of technologies for reducing product development times and cost as well as for addressing the need for customization, increased product quality, and faster response to the market requirements [2]. Digital manufacturing has become a common trend worldwide as computer-integrated manufacturing systems have eliminated data handling errors and enhanced decision making. Virtual Reality (VR) technology, Computer simulation using CAD modelling tools, and finite element analysis have assisted manufacturing engineers to reach decisions faster, while reducing errors [3].

This would ensure that activities, such as design, planning, machining, etc., are done first-time-right without the need for subsequent re-work and modifications. On the other hand, cloud computing has already managed to spread across many different industries and numerous users around the world, despite the fact that it is clearly a philosophy born in the 21st century as a natural outcome of globalization [4] and as the shift of industrialized countries towards a more service-oriented society model [5]. A massive

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increase in the amount of collected data, leading to "datasets whose size is beyond the ability of typical database software tools to capture, store, manage and analyze", known as Big Data, can be observed in the last years [6]. However, the effective exploitation of Big Data encloses great challenges and requires novel approaches and tools in order to maximize its impact [7, 8]. As a result, the challenges concerning the integration of distributed manufacturing resources as well as the cooperation and information exchange among different manufacturing sites, departments and organizations can be tackled in an efficient way [9]. Human skills undoubtedly require upgrade to handle the key enabling technologies sufficiently, including machines as cyber-physical systems, cloud platforms, human-robot collaboration, and smart devices. The present paper contributes in this direction by presenting the transformation of manufacturing systems towards Industry 4.0 and the concurrently change of the required skills through the transition of traditional education practices to Education 4.0. This shifting from the traditional Teaching courses to Education 4.0 is realised through this paper by presenting a Teaching factory.

Regarding the structure of the present paper, after this introductory section, the transformation of the manufacturing systems to Industry 4.0 is presented in detail in Sect. 2. Section 3 presents the expected change of the education system, while Sect. 4 presented the Teaching Factory concept. Finally, Sect. 5 compiles the conclusions.

2 Manufacturing Transformation to Industry 4.0

2.1 Traditional Manufacturing

During the previous decades a number of technologies have emerged to support all manufacturing phases. For most of them, an extended testing period was required until these technologies were adopted into the common practice.

In the traditional practice, after communicating with the customer and receiving the requirements for a new product, the design phase begins.

In this phase the design of the product is realized by the responsible engineers using Computer Aided Design (CAD) software which belongs to the standard procedures of manufacturing companies, while it is being constantly evolved [10]. Using CAD, the engineers are able to perform product designs faster compared to the handmade designs and therefore drastically increasing not only their productivity, but also the creativity and the job satisfaction [11]. The analysis of the CAD geometries to extract knowledge on the physical properties (mechanical, electrical, etc.) of the product is performed using the so-called Computer Aided Engineering (CAE) tools to determine the robustness of components and assemblies [12]. Through simulation and optimization methods, the CAE tools analyse the physical properties of the designed parts, providing meaningful insights that support effective design.

Before the production phase, the production planning engineering team creates the schedule for the resources of the shop-floor [13]. Scheduling can be performed using various methods and criteria based on the objectives that need to be fulfilled [14]. Meanwhile, the manufacturing enterprise has to ensure that the required resources will be available at the time of production, through inventory tracking and effective supplier management [15].

After the production schedule is created and the manufacturing tasks are assigned to the resources, the Computer Aided Process Planning (CAPP) and Computer Aided Manufacturing (CAM) tools process the CAD information and generate code for computer numerical control machine tools and robots. CAM may also support adaptation in the case of an unexpected availability of a resource, providing the capability to generate a new numerical code for a part, through the machine specific post-processors via unified data modelling [16].

Two major parts of the production are the manufacturing processes and the assembly. During the manufacturing phase, on-board supervision mechanisms on the manufacturing resources provide real-time information about the status of the resource and the progress of the process [17]. Nevertheless, this information is usually consumed at the time of its generation and it is scarcely assessed to conclude into actual knowledge of the production. Regarding the assembly phase, the research interest has generated mature results that are already applied in production. Robot automation in assembly affects positively the increase of productivity, especially in the assembly of heavy parts [18].

In the subject of the maintenance of machine-tools and equipment, preventive maintenance strategy is the one that is most commonly used in industry. Preventive maintenance, as a maintenance approach, is introduced to inhibit the equipment failure before it actually occurs [19]. Preventive maintenance actions are usually performed without considering the condition of the resource to be maintained. Therefore, unnecessary maintenance actions are performed increasing the operational costs of the industries.

Not all manufacturing companies employ all the aforementioned technologies. Especially small SMEs usually aim to strengthen some specific phases of their production, or they gradually proceed to the digital era, avoiding risks from the implementation and the investment cost of cutting-edge technology [20].

Despite the increase in productivity that these software systems provide, they still lack the capabilities for seamless information transfer and collaboration.

2.2 Industry 4.0 Transition and Requirements for New Skills

The transition to the Industry 4.0 is facilitated through the advances of the technologies related to Augmented Reality (AR), Information and Communication Technologies (e.g. Cloud and networking), smart sensors and others.

2.2.1 Key Enabling Technologies for Industry 4.0

AR is a novel human–computer interaction tool that overlays computer-generated information over the operator's field of view. The information that is provided to the user of the AR technology is context sensitive as it is usually depended on the location of the user and the object that they observe, providing an additional level of perception [21]. AR has already been demonstrated as a solution in many applications, in manufacturing and other fields [3].

Cyber-Physical Systems (CPS) are open, linked-up systems that operate flexibly, cooperatively (system-to-system cooperation), and interactively (human-to-system cooperation). They link the physical world seamlessly with the virtual world of information technology and software [22], and to do so they use various types of available data, digital communication facilities, and services [23]. CPS are closely related to the Internet of Things, where seamless communication among physical objects is achieved through embedded systems and communication networks [8].

A step forward is the integration of the digital tools related to product development into Cloud platforms, in order to enhance collaboration among the various actors at this stage of the product lifecycle providing ubiquitous access to information [24]. It can be concluded that the latest advances in ICT technologies are the means for the interconnection of the different elements of a manufacturing system towards a digitalized ecosystem. Integration standards with semantic representation of information, such as OPC-UA, along with Web-services and wireless sensor networks enable the seamless communication among tangible resources and humans. Especially, with the use of mobile and wearable devices humans enter the cyber world and communicate with machines.

2.2.2 Introduction of Enabling Technologies to Industry 4.0 Workflow and Required Skills

The Industry 4.0 paradigm introduces a new workflow for production systems by integrating the latest advances in Information and Communication technologies. From the very first step of the requirements collection, the social media enable customers opinion retrieval in a crowd sourcing manner [25]. As far as product design is concerned, AR is becoming a major part of the prototyping process. In collaborative VR/AR systems, the 3D models are displayed in a collaborative design session. In this phase, the AR technologies mainly involve engineers whose existing technical skills do not require radical enhancement, but may benefit from the advanced product visualization. Nevertheless, they need to familiarize with the concept of AR and understand its capabilities. Furthermore, the potential of cloud technologies in collaborative design is well-discussed in [26]. However, the design for X philosophy is required in order to achieve the goals set by the manufacturing company [27].

In an AR-based machining simulation environment, the users can gain awareness on the process information overlay, e.g. cutting parameters, and axes movement. The advantages of applying AR in these applications are that the user can accumulate knowledge and information when operating on real machines. The use of IoT devices for the real-time monitoring systems for the manufacturing resources, towards a CPS approach, may generate meaningful information that can be delivered via AR to production line operators [28, 29]. However, this novel information provision is intended also for employees with technical education. Therefore, the technical workforce should be capable of processing main operating characteristics and performance indicators related to the process and the resource and decide on potential changes. Specifically, this capability can support the identification of disturbances in production prior to their occurrence, supporting agile reaction [30].

Maintenance activities, e.g., preventive and corrective maintenance, are performed according to pre-defined procedures of the maintenance tasks. The CPS can support the condition-based preventive maintenance through the monitoring of the actual status of the manufacturing resources [31]. Maintenance technicians need to be trained in the respective procedures, and they sometimes need to seek help from supporting systems and experts [32]. AR technology shows merit in the maintenance applications in two aspects. Firstly, user interfaces can be rendered in a ubiquitous manner so that the operator perceives the instructions with less effort.

Secondly, user interactions in the AR environment can facilitate maintenance data exchange and allow remote collaboration to be achieved intuitively, while the on-spot technician performs the task [33]. Moreover, the collaboration through mobile devices in a social media manner facilitates the problem-solving potential, especially when dealing with unexpected events in the production [34]. The use of AR in actual production environments requires a workforce that is highly familiarized with it. This is firstly a safety issue, due to the limitations that AR projections introduce to the visibility of the user, while also it may lead to dizziness and increased cognitive load if used for extended periods of time.

During assembly, except for AR supported assembly [35], human-robot collaboration is a major enabler for increasing production rates while maintaining high quality in operations that involve humans. Hence, the operators need to be able to work inside a hybrid work cell and be familiar with the technology that is exploited to facilitate this collaboration [36]. In these situations, high alertness of the operator is critical while also following the strict task sequencing that the production planning has generated to make human-robot collaboration effective. The use of sensors, mobile devices, wearables, and context sensitive data provision transforms the operators of a digitalised manufacturing system into Operators 4.0. Thus, advanced learning models for machines are important so that humans and machines could develop skills that complement each other under any working conditions. One future research direction is an approach for “human-in-the-loop” machine learning, which enables humans to interact efficiently and effectively with decision-making models [37].

The integration of the Industry 4.0 technologies can be performed gradually without necessarily introducing radical changes in the production. This transformation is depicted in (Fig. 1). Nevertheless, the way of thinking about managerial issues and the approaches to decision making, need to adapt to the Industry 4.0 philosophy. This mostly affects the approaches for the data handling and the related software selection. Therefore, an important skill for the future engineers is to be able to distinguish the information related to the current task that can actually give value and support decision making. And based on this information, the selection of the appropriate software systems that will provide integration capabilities and process the data captured, towards improving the production processes through the accurate definition of the corresponding KPIs [38]. Furthermore, an open-minded systemic thinking will allow future engineers to adopt emerging technologies without delays.

Summarising this section, it is possible to aggregate and categorize competencies into four main groups – Technical, Methodological, Social and Personal competencies. [39] As it can be observed, the roles that are close to the production processes begin to require organizational skills to be able to function in the emerging requirements of the Industry 4.0. In addition, the executive roles require some technical knowledge on the

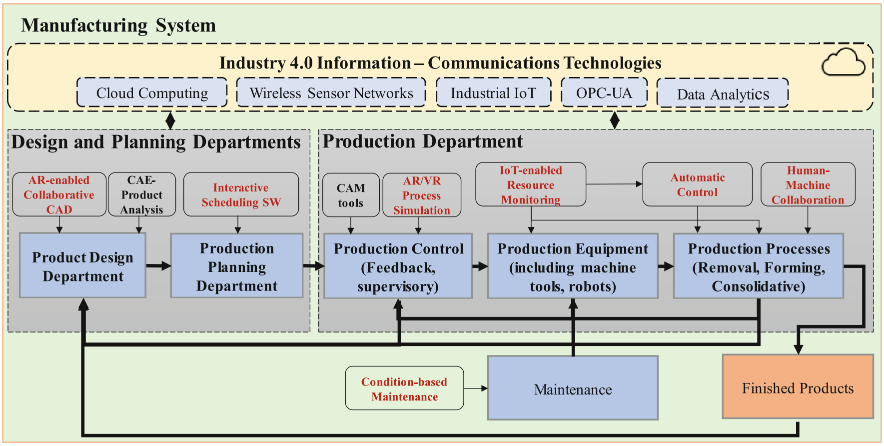

Fig. 1. Manufacturing Industry 4.0

production processes and the applied technologies, in order to exploit the value that is generated in the lower levels of the production. The skills and competences that are emerging from the introduction of the Industry 4.0 technologies, along with their importance to the roles of the employees are depicted in (Fig. 2).

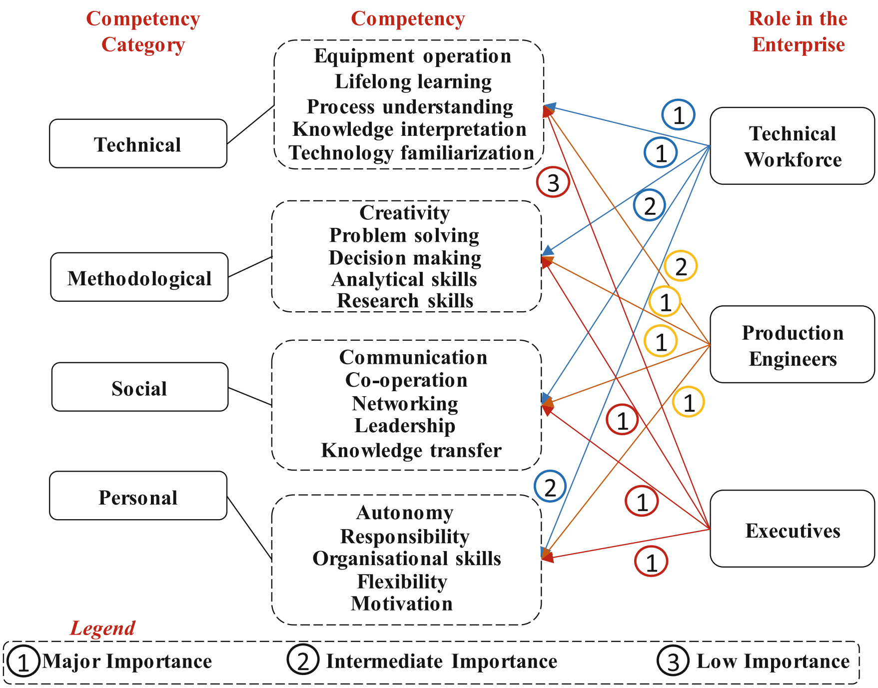

Fig. 2. Competencies for Industry 4.0 and importance to the roles in the enterprise.

3 Education Transformation to Industry 4.0

This section presents the rising needs for upgrading the education, and its directions, to create skilled and competitive employees for the digital factories of future.

According to the World Bank database, about the 20% of the employees of the developed countries, work in the Industrial sector. This is a very high percentage which can be translated to thousands of jobs, denoting the high significance for these people to update their skill in accordance with the evolution to the Industry 4.0 paradigm. Upgrading the skills of the workforce, can contribute to the future protection of their competitiveness in the market. Berger in [40] presents positive prospects for talent and employment, with an estimation increment of 10 million jobs related to the industry 4.0 between 2015–2035.

According to Berger in [41], the digital factory ecosystem can be the connecting point between education and Industry 4.0 needs.

Based on this ecosystem there is a chain which connects: (i) Government, (ii) Manufacturers, (iii) technology companies, (iv) Venture capital, and (v) University. In detail, the Government should provide grants and tax incentives to the research and innovation. On the other hand, the manufacturers should have the will to implement new technologies and new processes on a global market scale, while the technology provision companies should transform the new ideas and technologies into new business models and products. Finally, the venture capital should invest on testing and proving new ideas, while also supporting Universities to perform research and developments. The development of new technologies and processes from the university, will ensure that the aspiring engineers will be equipped with the adequate competences and skills in order to be a driving force in the industries of future. Education and technology consist the main vehicle for facing all the challenges, barriers, and needs for the Industry 4.0 workforce skills (Fig. 3).

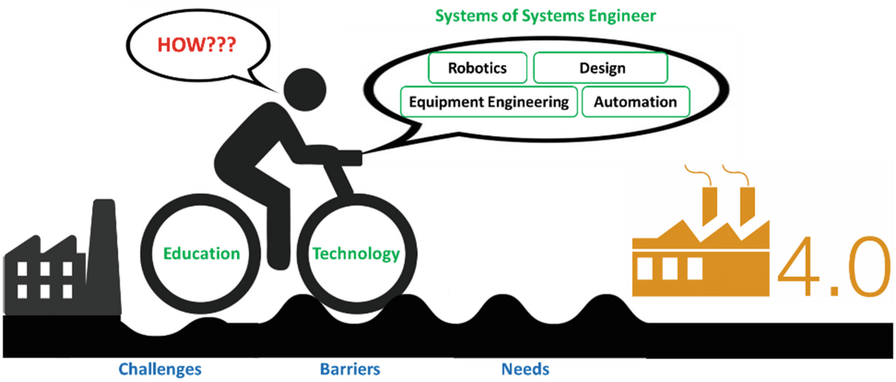

Fig. 3. Definition of Education 4.0 challenges, barriers, and needs

The education system could be modernized by imitating the industrial revolution (Fig. 4). Particularly, from the apprenticeships which were the dominant education practice in the decades of 50'–60', education was transformed into mass education through the universities, and nowadays, the universities have started to make online and digital Teaching towards personalized Teaching content.

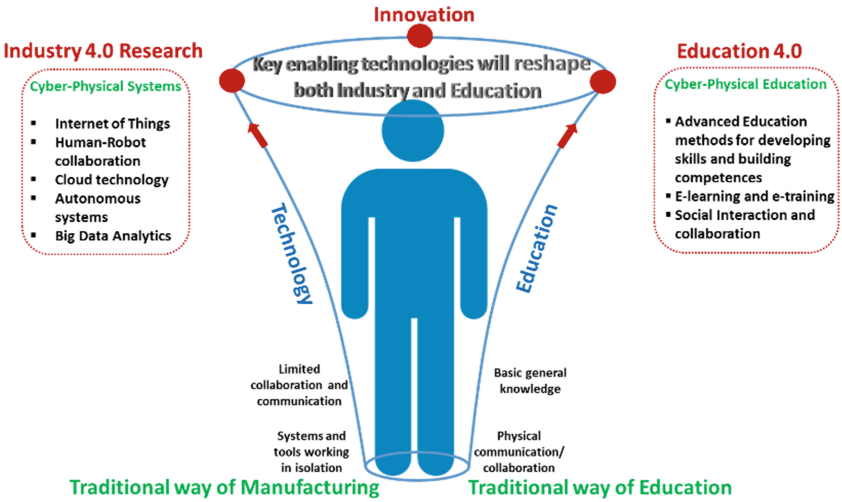

Fig. 4. Definition of Education 4.0

Table 1 shows the dominant knowledge requirements for the modern manufacturing systems, versus the knowledge requirements for the digital factory. As we can see in Table 1, the basic general knowledge around engineering has been transformed into Intelligence, while their capability to perceive their environment, a complex ecosystem with human operators and CPS, plays now a very important role, especially in dynamic production systems which change their workflow according to the production requirements. Moreover, the knowledge of using specific IT tools has been generalized to a capability to easily adapt to various IT tools, with the Teaching aptitude of the employees to be fast adaptive to every new tool or a new version of existing tools. Finally, the social interaction has been added to the digital factory skills requirements, since the good communication of manufacturing networking throughout the supply chain is nowadays the core competitive advantage.

Table 1. Skills for Engineering Education 4.0

Modern Factory knowledge	Digital Factory knowledge
Basic general knowledge	Intelligence
-	Senses to perception
Knowledge on using manufacturing equipment and specific IT tools	Advance knowledge on using various IT tools
	Teaching aptitude
-	Experience
Experience	Ability to improve
Ability to improve	Creativity
Creativity	Social Interaction
-	

According to a recent study of WEF (2017), about the 35% of core skills will change between the years 2015–2020. In the same research, a ranking is performed between the top 10 skills in 2015 and the 2010, with the first 3 skills for the 2015 to be: 1st Complex problem solving, 2nd Coordinative with others, 3rd People Management, for which the 2nd and the 3rd skills for 2020 to be replaced with Critical thinking, Creativity, respectively. In prevalent the skills of 2020, two new skills have been added, which are: Emotional Intelligence, and Cognitive flexibility. The authors in [42] present an industrial Teaching model comprising 4 steps:

- Interdisciplinary and development of high socio-technological systems
- Versatility, Adaptability, Creativity
- Intelligence and Teaching aptitude
- Entrepreneurship and Experience

Few years ago, [43] presents the evolution of the Teaching Factory concept and its application two real-life industrial pilot cases from the automotive industry. The Teaching Factory aims at two-way knowledge communication between academia and industry. Both knowledge channels of the paradigm were tested on two real-life industrial pilots among a university and a construction equipment factory, as well as an industrial automation company respectively. The results of this work reveal equal benefits for both sides. From the industrial side, they secure a connection to the ever-changing technologies and the on-going research, while providing new ideas and solutions beyond the traditional company's process. For the academia, Teaching factories offer a useful connection between the theory and the generated knowledge and their integration under real cases, especially considering that the participants lack related experience. Finally, Teaching Factory encourages entrepreneurship in universities and innovation within companies. The actual benefit of the economic system by adopting new techniques towards Education 4.0 is illustrated in Fig. 5.

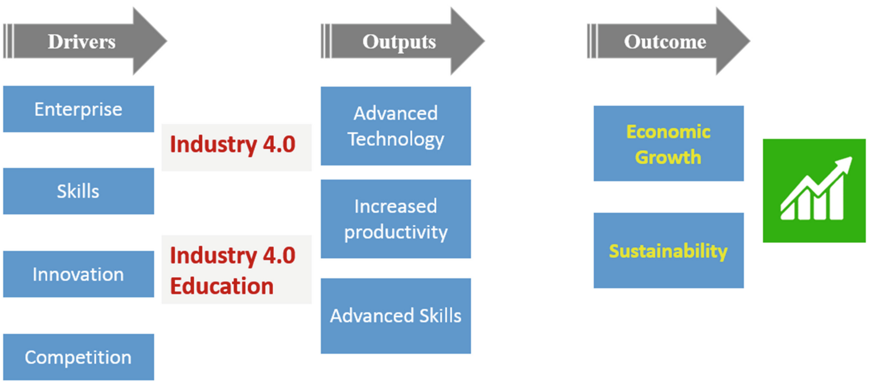

Fig. 5. Teaching factory 4.0 benefits

4 Innovative Teaching Factory Approach

Following the findings presented in the previous sections, related to the requirements for new skills and the adaptation of education to fulfill the demands of Industry 4.0, it is apparent that an innovative Teaching Factory approach is essential for the academia and the industry. The proposed Teaching Factory approach upgrades the human operator skills and competencies needed for the 4th Industrial evolution paradigm as presented in detail in the previous chapter.

This innovative Teaching Factory approach refers to the under-graduate students of engineering science university departments. Therefore, it contributes to the skills and competences required mainly for production Engineers. The proposed approach is already applied to the undergraduate curriculum and includes 4 steps, where the participants, separated in groups, go through the requirements collection to the design and the production of a complex product [44].

It is of high importance for students to be familiar with a structured way of thinking for solving an industrial problem, starting with the collection of requirements, followed by the specification of the environment that the product will be developed, and after that the actual design and the implementation. The previous structured way of thinking is very important for their professional career later. The proposed Teaching Factory Paradigm is illustrated in Fig. 6.

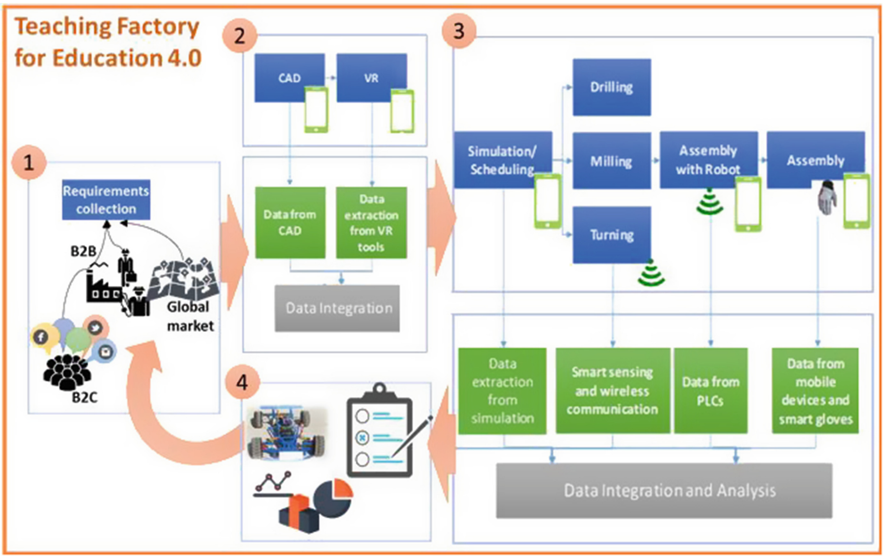

Fig. 6. Teaching Factory for Education 4.0

This teaching factory paradigm aims to educate young Engineers in the Industry 4.0 workflow that is presented in Sect. 2.

The Teaching Factory concept is based on the knowledge triangle notion (teaching, research, and technology transfer) aiming to become a new paradigm of both academic and industrial learning [42, 45]. The first step is the requirements collection. The students should initially recognize the target group of market, whether the product will be provided in the end-consumers, business companies, or the regional market; all these aspects affect the way that the requirements collection will be performed. For example, if the target group of products is other industries in a business-to-business manner, then the students will have the opportunity to organize a number of meetings (web-meetings and on-site) in order to collect all the appropriate information, to start a design that meets the industrial needs. This is achieved through the close collaboration of the university with the local industry. If this product is a regional product, then the frugal innovation aspects should be considered during the design, which will be based more in the culture of the specific area, and the affordability of the product. [46] Finally, if the students design a product that will be provided in the end-consumers, then, the exploitation of the social media and the comments in several forums should be considered in order to collect the appropriate requirements. In this case, several open source software tools could be considered to facilitate the process.

The second step is the design of the product. In this stage, the students are called to prepare the initial design of their product in a CAD software. The part designs from each group are stored in a central database. The product designs are then used for an augmented/virtual reality evaluation workshop. The participants are called to validate their designs in real scale using Augmented Reality and then to simulate the assembly process using Virtual Reality [47]. In the first phase, the Teaching Factory participants get to interact with their design, examine it and detect any flaws that could drastically affect the final assembly and the functionality of the final solution. As the participants lack the experience to early detect these flaws and to produce a first-time-right design, this digital prototype and the realistic interaction with it facilitates them to detect their errors, in this early stage. Moreover, through the virtual reality simulation of the assembly, they may test the assembly of the designed parts. The time it takes them to complete the virtual assembly is tracked and stored; any delays detected at this stage should be noted as it may reflect potential errors in the initial design. The manufacturability of the design is validated through tele-conferences with the local industry [48].

The third step includes the manufacturing and assembly of the parts of the product. Based on their designs, the participants are called to simulate and schedule a production line that will be manufacturing the designed product. The students are called to use novel software packages that support the simulation of the production line and the scheduling of the task so as to meet different demand profiles. The provided cases simulate realistic scenarios that the students will be called to face in their future involvement in manufacturing.

Additionally, in the proposed framework, the data from each group are directly stored in a database, where the participants may compare their proposed shop floor setup and the achieved performance with the other groups, evaluating their own proposals. This procedure aims to involve the group in a self- evaluating improvement, during which they familiarize with a simulation software and eventually the requirements of a production line. After simulating the production and familiarizing with the theoretical background of each process required, the participants are called to manufacture the parts for their product. The Teaching Factory offers them three processes to utilize: milling, drilling and turning. Each station/machinery is upgraded in a Cyber- Physical System (CPS) equipped with sensors that monitor the process and is connected with a wireless network that collects all the recorded data and stores them in the database. Each group uses the given near field communication (NFC) card to state their group number and the starting time of each process, and under the supervision of an experienced operator of the machinery, manufacture the required parts. The data from the installed sensors are recorded and sent to the central database and also to a mobile device application from which the participants may read the recorded data in real time, monitor the status of the machine and notice any deviations. Through this part of the Teaching Factory 4.0, the participants familiarize themselves with the Industry 4.0 technologies that shape manufacturing and start to be integrated in production lines. The assembly of the final product is executed in two parts. The first part is performed with the aid of a robotic arm, also under the human-robot collaboration framework. Since the majority of the assembly processes in modern manufacturing is performed by automations, it is important that Education 4.0 integrates these approaches in the courses and Teaching workshops. The aspiring engineers are called to collaborate with the robot in an assembly process, using augmented reality goggles to see the instruction what to do and the trajectory of the robot when it is moving, and also communicate with it through a smart watch. Through the smart watch, the operator may interact wirelessly with the robot, confirming the completion of an action, seeing useful notifications and validating the completion of the whole task. During the task, each group collects data about the required time and also from the PLC of the robot, thus creating a useful dataset about the task, from which they may draw some information. Following the directives of digitalization introduced by Industry 4.0, the participants wear a smart glove during the assembly process. The smart glove hosts sensors that track the movements, grasps and assemblies of the operator creating a map of its movements. Using the NFC card, each group indicates the beginning and competing time of each assembly step. Moreover, to support this process, the operator may use a mobile device application that utilizes augmented reality to visualize assembly instructions for the standardized parts of the designed product.

Through the recorded data, each group may evaluate their performance in the assembly process, by monitoring the required time and detecting redundant movements that could be a result of an error in the original design or manufacturing.

After the completion of the third step, each group tests the developed product, in a sequence of trials. Completing the Teaching factory 4.0, the participants acquire a set of highly useful skills that will support their future careers in manufacturing. Apart from familiarizing themselves with the traditional steps of product design and manufacturing tools, the aspiring engineers become educated in the technologies dictated by Industry 4.0 and will shape future manufacturing. Teaching Factories, following the technological breakthroughs, need to evolve so as to provide the workshops that will support the Education 4.0, making the aspiring engineers used to working in the industrial environments, in realistic conditions and considering resources and design limitations, as they will be called to do in their future careers.

All the steps of the process were upgraded to provide digital data on the task: mobile devices apps were used in the design phase steps while embedded sensors provided data coming from the machines. Making the students familiar with these features that are forming the cyber-physical systems of future production lines, prepares the aspiring engineers for the manufacturing environments that they will work in. Data integration and analysis of the gathered data provides an insight for the students to better understand the manufacturing phases and evaluate their performance through the task. The major aspects from the proposed Teaching Factory are presented in Fig. 7.

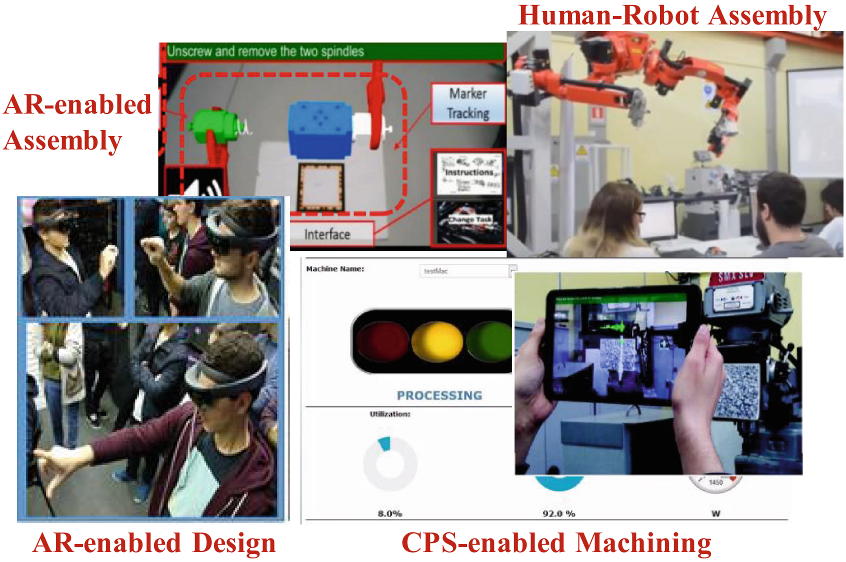

Fig. 7. Major aspects of the proposed Teaching Factory

5 Conclusions

The present study investigates the new requirements for employee's skills raised from the new manufacturing paradigm of Industry 4.0. The new manufacturing workflow is presented along with the needs for new skills and competences. The model of Education 4.0 is presented based on these needs. Finally, a Teaching Factory concept is proposed following the requirements of Industry 4.0 and Education 4.0. The proposed framework aims to facilitate the training and to aspire engineers in better envisioning and evaluation of their product designs, raising their interest in product design and manufacturing, and eventually increasing the overall effectiveness of the Teaching Factory. Furthermore, young engineers are familiarized with the novel digital technologies that are expected to shape manufacturing in the years to come and broaden the horizon of thought of the participants towards Industry 4.0 paradigm. The integration of innovative technologies has the potential to improve the insight of the designer on the final product thus increasing error detection in the early stages of design and the confidence of the participants for their design. A major outcome of the proposed Teaching Factory is the training of young engineers of being able to work in a group and deliver a tangible result in near-real manufacturing conditions [49].

Future enhancement of the proposed Teaching Factory aims to complement the curriculum with workshops on the development of the specific Industry 4.0 applications. Hence, the young engineers will learn in depth the technologies for the development of the AR applications, CPS monitoring systems, human robot collaboration etc. This knowledge will make them capable of proposing the adoption of these technologies in their future work in industry. Therefore, major steps towards the adoption of Industry 4.0 practices in real manufacturing systems will be performed.

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