THE EXCELLENT ADVANCED MANUFACTURING 4.0

Report on the State of the art of Advanced Manufacturing and HVET/VET in Europe

01

Learning dialogues

Co-funded by the
Erasmus+ Programme
of the European Union

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Acronyms and Abbreviations

AR	Augmented Reality
AM	Advanced Manufacturing
AMS	Advanced Manufacturing System
AFM	Spanish Association of Machine Tool Manufacturers
AI	Artificial Intelligence
BDA	Big Data Analytics
CPS	Cyper-physical-system
CPSS	Cyber-physical social systems
CPPS	Cyber-physical production systems
DHBW	Duale Hochschule Baden Württemberg BD
EACEA	Education, Audiovisual and Culture Executive Agency
EXAM 4.0	Excellent Advanced Manufacturing 4.0
HVET	Higher Vocational Education and Training
I4.0	Industry 4.0
IaaS	Infrastructure as Service
IoT	Internet of Things
IIoT	Industrial Internet of Things
KET	Key enabling technologies
M2M	Machine-to-machine
OMR	Optical Mark Recognition
PaaS	Platform as a Service
RFID	Radio Frequency Identification
RP	Rapid Prototyping
SaaS	Software as a Service
SCM	Supply Chain Management
SME	Small-Medium-Enterprise
VET	Vocational Education and Training
VR	Virtual Reality
WP	Work Package
XaaS	Everything as a Service

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1 State of the Art of Advanced Manufacturing and Training in HVET/VET Institutions in Europe

ABSTRACT

The applications of Industry 4.0. innovations, such as Smart Factory and Smart Production, change the future nature of work and call for different competencies of the workforce. Therefore the focus of Industry 4.0 is - despite increasing Automation – the human factor. Industry 4.0 places new demands on the employees - through new technologies, new organisational forms, and work processes. Without qualified employees, companies will not be able to sustainably secure technology leadership.

The so-called fourth industrial revolution is characterized by individualization (even in series production) or hybridization of products (coupling of production and service) and the integration of customers and business partners in business and value-added processes. Essential components are embedded systems as well as (partially) autonomous machines that move in and through environments without human control and make decisions independently, and developments such as 3D printers. The networking of technologies and objects provided with chips results in highly complex structures and cyber-physical systems (CPS) or the Internet of Things.

In the context of Industry 4.0, educational research predicts that higher qualification requirements and related competences development will increase for all employees. This will be the case, especially for the lower and middle qualification level, due to greater complexity, abstraction, more comprehensive problem solutions, and the interaction of cyber-physical systems in comprehensive overall processes (Kagermann et al., 2013).

The range of tasks of human work will shift more towards complex, non-automatable tasks with higher qualification requirements (Bonin et al., 2015). New content and methods need to be incorporated into apprenticeships and advanced training, while topics like cyber-physical systems, robotics, and social media play a key role in connected production. In the area of operations, at the specialist level, well-trained employees are needed who can actively shape work processes, optimize them continuously and consciously reflect developments in the company. They must have extensive knowledge of, for example, project management, lean management, or total quality management and be able to apply their relevant methods.

In the context of Industry 4.0, the study of future trends, qualification requirements, competences and skills development, and future job profiles will be discussed. The focus lies on the requirements for professional training and further education, specifically in technical professions and academic education in the area of Advanced Manufacturing.

Key questions

Are core qualifications that are changing across different professions recognizable, e.g. related to process skills, IT skills, and problem-solving behavior? How can these ideals be conveyed?

"How?" to qualify specialists above a "machine operator". The "how?" encompasses the question of the design of professional images as well as the demonstration of concrete didactic consequences, e.g. the development of models for competence development and diagnosis, strategies for curriculum development and design, concepts in training and further education as well as teaching and examination concepts.

Kagermann / Wahlster / Helbig is describing the two trends in Industry 4.0: "On the one hand, conventional production processes with a strong division of labour are embedded in a changed structure and process organization and enriched with decision-making, coordination, control and accompanying service functions. On the other hand, the interaction of virtual and real machines, plant controls, and production management systems must be organized and coordinated." (Kagermann et al., 2013).

Qualifying, by education or training, does not necessarily indicate that the person is competent. Competence means the successful demonstration of competencies required in the qualification topic of I4.0.

In the context of future trends in Industry 4.0 training and education, the consortium will distinguish qualifications from competencies. Industry 4.0 qualifications constitute knowledge and skills that can be objectively described, taught, and learned, and are functional (Erpenbeck J., 1996), while the concept of Industry 4.0 competencies also embraces individual aspects of personality that are directed towards (vocational) utility. In this connection, the main aim of the development of competences is the formation of personality structures to cope with the requirements of change in Industry 4.0 within the process of transformation and the further evolution of economic and social life (Vonken, 2005).

INTRODUCTION

Industry 4.0 (I4.0) is mainly understood as a new phase of the industrial revolution, which, after the mechanization, electrification, and computerization of the industry, will now transform with the "Internet of Things", a more intelligent and worldwide networking of machines, storage systems, and resources to a **cyber-physical system – CPS**, the widespread usage of Industrial Internet and alternative connections that ensure the networking of dispersed devices. (Kagermann et al., 2013). The scenarios of CPS are combined with a whole range of other technical developments, such as 3D printing, adaptive robotics, machine-to-machine (M2M), cloud computing, app economy, business model innovation, smart factory, mobile devices, etc. I4.0 aims to develop a completely new concept in production automation.

The new technologies of intelligent production or advanced manufacturing involve a fundamental change in the division of work between humans and machines. This will bring about substantial consequences for the tasks, quality of work, and **competencies of the employees.** Since there is still a lack of knowledge about the **characteristics of the new working processes** so far, potential barriers to implementation and acceptance represent a substantial risk for enterprises aiming at introducing intelligent technologies.

I4.0 will influence our working environments significantly and it will change processes in purchase, production, manufacturing, sales, or maintenance by including concepts as smart manufacturing, smart maintenance as well as a high degree of automation and integration in all enterprise processes. As a consequence, employees will be confronted with **transformed work processes** and business models as well as with new technologies. Processes will become interconnected and more complex.

This transformation of the work environment will change the job profiles and therefore requires employees to be outfitted with a wide range of competencies. Experts and production specialists both have to answer technical questions and have to deal with organizational problems. Typical technological challenges are understanding and designing complex, automated production systems in process chains, e.g. the integration and commissioning of a new production cell in a production chain (Schuh, 2017). Organizational challenges essentially include understanding complex manufacturing processes and workflows and their independent planning, optimization, and control, for example, the conception of manufacturing processes. Well-trained employees who can actively shape and continuously optimize work processes, and continually optimize them, are needed for the examined activities in production, also at the specialist level (Kagermann et al., 2013).

To successfully get through the transformation towards I4.0, a clear definition of the competencies for I4.0 is needed. Furthermore, a clear description of the relationship and connection between these competencies can provide the foundation for competency development in the future. The best way to address this point is the structured competency model (see EXAM 4.0 WP2A3 Report), which addresses I4.0 competencies for graduates.

WHAT ARE INDUSTRY 4.0 AND ADVANCED MANUFACTURING?

Industry 4.0 is a meta-term for the further development of production and value creation systems by linking the real and the digital world. This link is created by self-controlling CPS, which is equipped with embedded systems. Industry 4.0 describes the vertical (within a company) and the horizontal linkage of these CPS (both across several company areas as well as across several companies along the supply chain) for the efficient, decentralized, and flexible production of products or implementation of services.

Industry 4.0 can be considered as a subcategory of the Internet of Things (IoT) technologies and in the literature, it is commonly referred to as well as "Smart Manufacturing", "Smart Industry", "Smart Factory", etc. Further, the Industry 4.0 concept incorporates several key technologies such as Big Data/Analytics, advanced human-machine interfaces, smart sensors and actuators, advanced robotics, artificial intelligence, security authentication, cloud computing, location tracking technologies, 3D printing, augmented reality, and wearables, etc. It should be noted that it is not limited to automation of a single production facility but refers to the whole production chain, including the supply chain, material sourcing, warehousing, production, and delivery.

The transition to Industry 4.0 is restricted neither to specific sectors nor to individual areas of a company. This means that all types of work will – to differing degrees and in a variety of ways – be subject to change and can be supported by assistance systems based on the specific needs that exist.

The main motivation of Industry 4.0 is the connection and integration of manufacturing and service systems to provide effectiveness, adaptability, cooperation, coordination, and efficiency.

On the one hand, the main focus of companies is, on the productive and innovative potential in the organization, on the continuously and comprehensively customer-oriented renewal of products and services and thereby gain lasting competitive advantages. For them, the focus is on the activation and development of workability, the individual and collective competencies based on task-integrated, cooperative, and self-directed work processes. They use this to expand earnings by opening up new business areas without, of course, foregoing process innovations that are critical to success to reduce costs. The demand for new, high-quality, and highly customizable products leads manufacturing companies to develop production environments that quickly adapt to product variations. Advanced manufacturing systems have promoted information as well as process integration in companies and have helped companies to transform from mass production to mass customization (Kotler, 1989); and beyond that to Industry 4.0. Industry 4.0 is the logical next step of the industrial revolution, characterized by the use of IT and electronics to push forward the automation of manufacturing processes, while machines take over parts of the human work in production (Tao et al., 2017).

On the other hand, companies are seeing the potential and opportunity in I4.0 and Advanced Manufacturing on reducing costs. This "low-road strategy" primarily uses instruments such as wage cuts and staff downsizing as well as outsourcing or computerized restructuring of processes ("reengineering") to reduce competitiveness simply by reducing costs to improve (Brödner, 2006).

In both cases, the main purpose of industrial transformation is to increase resource efficiency and productivity to increase the competitive power of the companies.

The idea of networking continues in Industry 4.0, in which all stages of the value creation process from planning to delivery to the customer are linked outside and inside the company ("intelligent" factory). Intelligent machines organize the manufacturing processes independently, service robots assemble new products with people, intelligent driverless transport vehicles independently carry out logistics orders. In addition to the intelligent factory, production and logistics processes are interlinked worldwide via the Internet to optimize the flow of materials, to prevent possible errors in logistics and production from occurring in the first place, and to be able to react flexibly to changing customer requirements.

In the modern workplace, I4.0 environment employees need domain or subject competency and process competences.

The use of the process chain of industrial value creation as a framework is essential because the integration of those involved (producers, suppliers, service providers, customers, etc.) into adapted, versatile value chains and business processes are one of the core objectives of Industry 4.0.

Industry 4.0 aims to connect resources and business processes vertically and horizontally within and across companies. Technical processes including their resources and (commercial) business processes in companies are vertically linked across different company levels as well as the information, communication, control, and management systems. This vertical integration merges the real and virtual worlds.

On the other hand, the processes and resources along the value chain are networked with each other. This networking is not limited to individual machines within a company but also overcomes company boundaries. The (mechanical) communication takes place horizontally between clients and manufacturers and continues within the entire supply chain at all company levels and functions. The networking of processes and resources along the internal and cross-company value chain is referred to as horizontal integration (Obermaier, 2019); (Kagermann et al., 2013).

Well-trained employees are needed who can actively shape work processes, optimize them continuously and consciously reflect developments in the company. They must have extensive knowledge of, for example, project management, lean management, or total quality management and be able to use their relevant methods. The work tasks are mostly very complex and are characterized by often contradicting requirements from the perspective of quality requirements for a product, the deadlines to be taken into account and the cost targets to be met. Besides, intensive interaction with superiors, other employees, and customers is required.

BUSINESS MODELS AND BUSINESS MODELS INNOVATION

St. Gallen Management Model

The new St. Gallen management system distinguishes six central categories. On the one level are the categories environmental spheres, stakeholder groups, and interaction issues that relate to the social and ecological environment. On the other level are the categories ordering moments, processes, and development modes, which refer to the internal view of the organization.

The St. Gallen Management Model describes an enterprise as a system of processes. Processes are routine processes that shape the everyday life of a company. In the superior mastery of these routines, especially in a short process time, it is an important prerequisite for entrepreneurial success. A distinction is made between management processes, business processes, and support processes. (Rüegg-Stürm & Grand)

- **Management processes**

  Management processes encompass all basic tasks related to the "design, direction (steering) and development of purpose-oriented socio-technical organizations". A distinction is made between normative orientation processes, strategic development processes, and operational management processes.

- **Business Processes**

  Business processes embody the core activities of a business, which are geared directly to customer value. They include the customer processes (brand management processes, customer acquisition processes, and customer loyalty processes), the service creation processes, and the performance innovation processes.

- **Support processes**

  This is where in-house services for the effective completion of business processes are accomplished. These include, for example, processes of educational work (learning processes) and personnel work (continuing education programs).

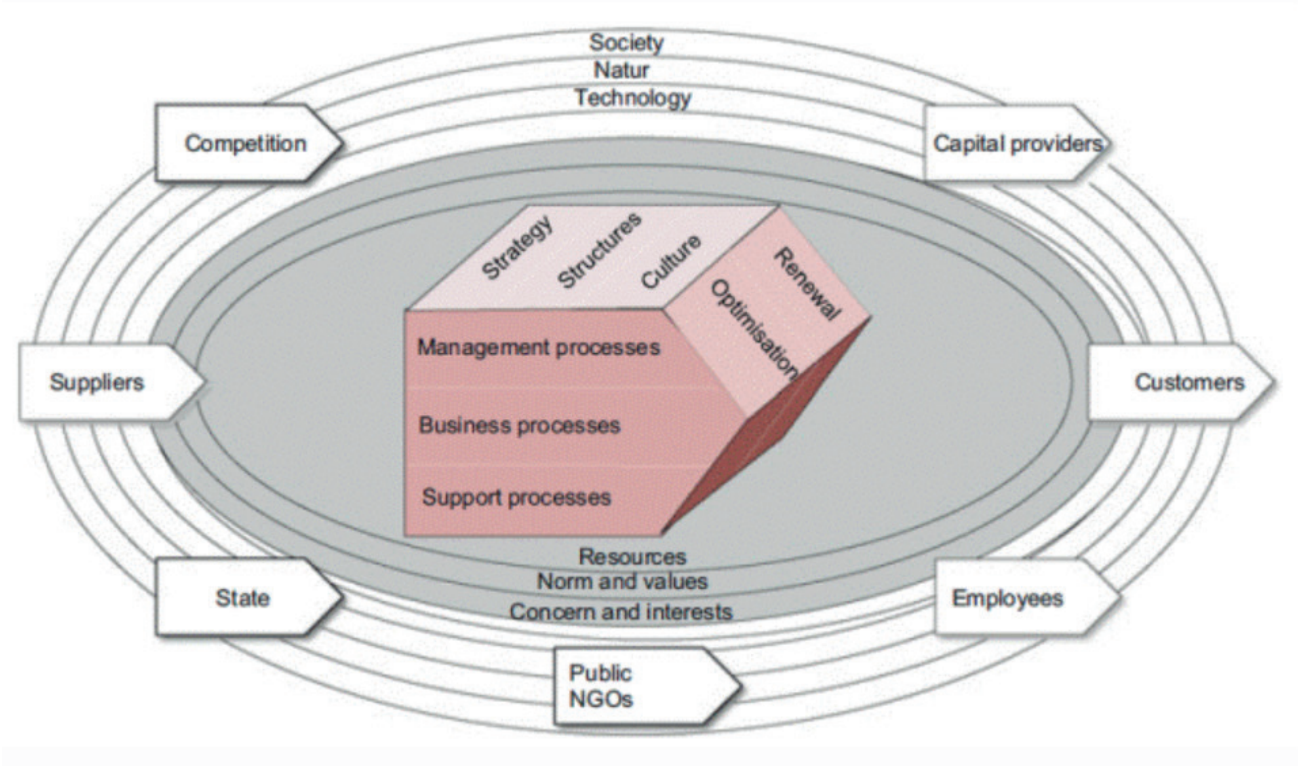

Figure 1: The new St. Gallen management model, (Rüegg-Stürm & Grand).

Industry 4.0 Business Model

Industry 4.0 is often discussed from a technological perspective of machine learning, algorithms, smart sensors, and connected assets. But the truth is, its biggest impact will be on company business models, especially those of well-established companies (Meinhardt & Pflaum, 2019).

Four ways to conduct the **digital transformation in manufacturing companies** have been identified according to the innovation degree applied that goes from modifying such a few elements of the business model through an incremental innovation, to the transformation of all the elements of the business models due to a radical innovation (see figure 2) (Osterwalder & Pigneur, 2010).

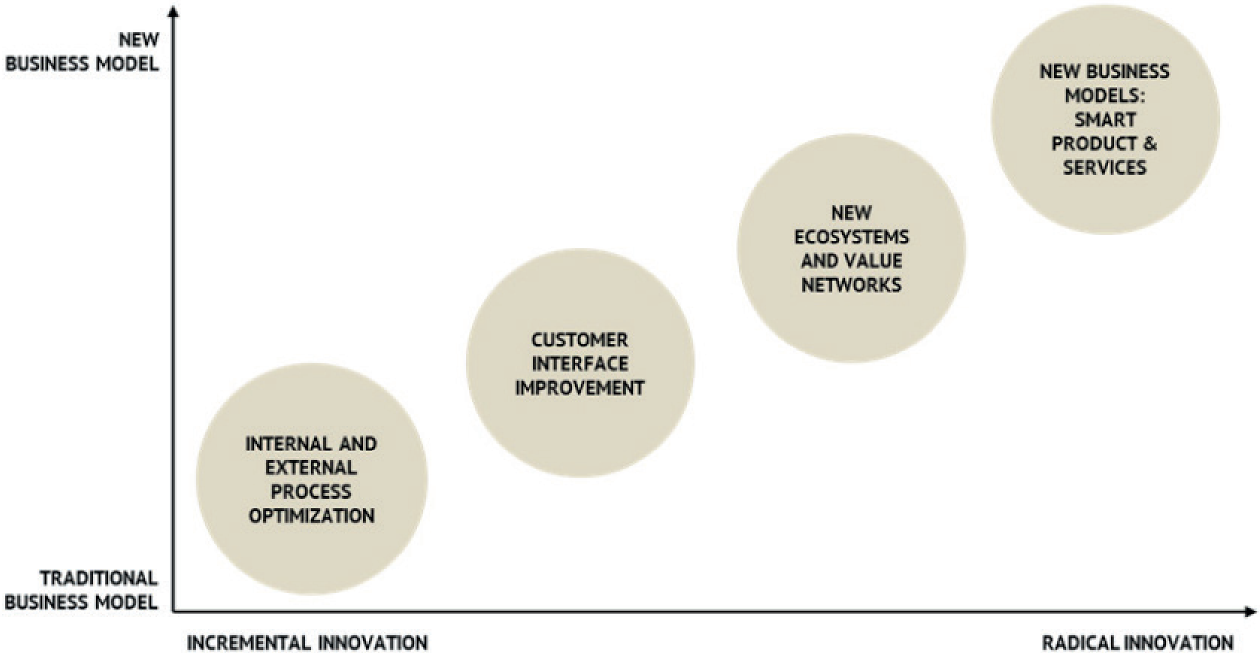

Figure 2: Elements of a Business Model (A.P. Osterwalder, Yves Pigneur, 2010).

The transformation of Industry 4.0 requires strategic workforce planning, constructing the right organizational structure, developing partnerships, and participating and sharing the technological standardizations, which are essential factors to drive technological advancements.

Industry 4.0 companies require new ways of creating and offering value through ecosystems that goes beyond individual value chains. The business model I4.0 should encounter a strategy and description of the value a company offers to one or several segments of customers and of the architecture of the firm and its network of partners for creating, marketing, delivering this value and relationship capital, and generating profitable and sustainable revenue streams (Osterwalder & Pigneur, 2010). A successful business model should have four fundamental building blocks:

- *The customer value proposition that fulfills an important job.*
- *The profit formula that points out how your company makes money delivering the value proposition.*
- *The key resources that value proposition requires.*
- *The key processes needed to deliver it.*

3 Industry 4.0 Technology Enablers

As described in the introduction, I4.0 is a broad concept that encompasses many of the mega-trends which are currently sweeping the business world such as digitalization and the associated technological concepts Internet of Things (IoT) and Big Data Analytics (BDA). As pointed out by Hirsch-Kreinsen (Hirsch-Kreinsen et al., 2018), I4.0 is "to a great degree compatible with the rapidly growing general focus in society on digital technologies and Internet, and with the dominant conviction that this is no less than a societal mega-trend". This chapter takes a brief look at the conceptual evolution of I4.0. The I4.0 is hardly a static concept; instead, it has evolved considerably over time. One interesting development is that the concept has morphed from a specialized and rather narrow concept focused on industrial production and the manufacturing context to gradually become a much more all-encompassing concept with nearly universal applicability. The following sections describe major I4.0 technology enablers and most important for Industry 4.0.

EMBEDDED SYSTEMS (CYBER-PHYSICAL INFRASTRUCTURE) AND MOBILE TECHNOLOGIES

Embedded systems, named as **Cyber-Physical Systems (CPS)**, can be explained as supportive technology for the organization and coordination of networking systems between its physical infrastructure and computational capabilities. In this respect, physical and digital tools should be integrated and connected with other devices in order to achieve decentralized actions. In other words, embedded systems generally integrate physical reality concerning innovative functionalities including computing and communication infrastructure (Zhong et al., 2017).

Concerning Industry 4.0, **the mobile internet** is vital for a connected production environment, for example regarding real-time data capturing and accessibility, object tagging, and internet-to-object communication.

One aspect of Industry 4.0 is the way manufacturing works is quickly changing with smart connectivity: machines, plants, products, warehouses, and tools communicate with each other. And thanks to mobile devices, they communicate with employees, too.

CLOUD TECHNOLOGIES

A cloud system or cloud computing technology refers to the computing components (hardware, software, and infrastructure) that enable the delivery of cloud computing services such as: SaaS (software as a service), PaaS (platform as a service), and IaaS (infrastructure as service) via a network (i.e. the Internet).

Cloud-based operating is another essential topic for the contribution of networked system integration in Industry 4.0 transformation. The term "cloud" in I4.0 includes **both cloud computing and cloud-based manufacturing and design**. Cloud manufacturing implies the coordinated and linked production that stands for "available on-demand" manufacturing. Demand-based manufacturing uses the collection of distributed manufacturing resources to create and operate reconfigurable cyber-physical manufacturing processes. Here, the main purpose is enhancing efficiency by reducing product lifecycle costs, and enabling the optimal resource utilization by coping with variable-demand customer-focused works (Thames & Schaefer, 2016).

ADDITIVE MANUFACTURING

The term Additive Manufacturing (AM) encompasses many technologies including subsets like **3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM)**, layered manufacturing, and additive fabrication. Additive manufacturing is a set of emerging technologies that produce three-dimensional objects directly from digital models through an additive process, particularly by storing and joining the products with proper polymers, ceramics, or metals.

VIRTUALIZATION TECHNOLOGIES (VIRTUAL REALITY (VR) AND AUGMENTED REALITY (AR)

Virtual reality (VR) is an artificial, computer-generated simulation or recreation of a real-life environment or situation. It immerses the user by making them feel like they are experiencing the simulated reality first hand, primarily by stimulating their vision and hearing, and is used prominently in two different ways:

- To create and enhance an imaginary reality for gaming, entertainment, and play (Such as video and computer games, or 3D movies, head-mounted display).
- To enhance training for real-life environments by creating a simulation of reality where people can practice beforehand (Such as flight simulators for pilots).

Augmented reality (AR) is a technology that layers computer-generated enhancements atop an existing reality to make it more meaningful through the ability to interact with it. AR is developed into apps and used on mobile devices to blend digital components into the real world in such a way that they enhance one another, but can also be told apart easily. Overall, the application of AR to the industry domain is relevant since it greatly improves the communication in product design and product development: it helps to identify and avoid design errors in the early stages of the development process, it reduces the number of physical prototypes and saves time and cost for enterprises. AR is considered a valuable tool for improving and accelerating product and process development in many industrial applications. The five major areas of application for AR in industry 4.0 are Human-Robot Collaboration, maintenance-assembly-repair, training, product inspection, and building monitoring. In the Human-Robot Collaboration domain, AR is used to create efficient interfaces to interact with industrial robots. In the maintenance-assembly-repair tasks, AR improves their own productivity and functions as an assistance system. In training operations, users can find in the AR a powerful solution to enhance their skills. In the inspection of the products, controllers can notice any discrepancies of items using powerful and versatile AR systems. Finally, in the building monitoring operations, AR highlights any error or deviation of a facility simply and intuitively.

AR improves the reliability and safety of robotic systems showing to workers the intentions of robots, reduces costs, and improves the performance of maintenance systems or it shows precisely any discrepancies of products superimposing models on the real object.

Virtualization technologies are based on AR and VR tools that are entitled to the integration of computer-supported reflection of a real-world environment with additional and valuable information.

DATA ANALYTICS (BIG DATA) AND ARTIFICIAL INTELLIGENCE (AI)

Even though the terms **data analytics/ science, machine learning, and artificial intelligence** (AI) fall in the same domain and are connected to each other, they have their specific applications and meaning. Data science and analytics focuses on data modelling and data warehousing to track the ever-growing data set. The information extracted through data science applications can be used to guide business processes.

Artificial Intelligence (AI) has come to be associated with robots and a machine-dominated world, enabling machines to execute reasoning by replicating human intelligence. The emerging AI applications that are currently shaping industry 4.0 journey include self-driving cars, human speech and face recognition, and interpreting of complex data and medicines, for example, cardiovascular medicine)

AI plays an essential role in an Advanced Manufacturing system (AMS) by providing typical features such as learning, reasoning, and acting. With the use of AI technology, human involvement in an AMS can be minimized. For example, materials and production compositions can be arranged automatically, and production processes and manufacturing operations can be monitored and controlled in real-time.

Data analytics and artificial intelligence make it possible to link data to gain insights on customers, grow the business, and optimize the speed and quality of logistics. As a consequence, manufacturing companies start to adopt advanced information and knowledge technologies to facilitate their information flow, a huge amount of real-time data related to manufacturing is accumulated from multiple sources. The collected data that occurred during R&D, production, operations and maintenance processes is increasing at exponential speed (Zhong et al., 2017).

COMMUNICATION AND NETWORKING (INDUSTRIAL INTERNET OF THINGS IIOT)

The **Industrial Internet of things (IIoT)** is the infrastructure of interconnection among objects. In manufacturing systems, each device is embedded with electronic software, sensors, and actuators and is connected to Internet networks. The IIoT enables manufacturing devices to exchange data within manufacturing devices and between manufacturing devices and their service providers or consumers. From the technical point of view, we can describe the IIoT as a combination of sensors such as RFID, other communication devices (i.e., embedded computers), CM applications, Enterprise Resource Planning (ERP) integration, and business intelligence technology.

From a communications perspective, **IoT and CPSs rely largely on mobile Internet**, i.e., telecommunication networks. The developments in the field of communication and networking technologies, together with unified and semantic information modeling based on web standards, are changing the structure of industrial networks, and became the prerequisite for actually implementing industrial IoT (IIoT) and CPSs.

Communication and networking can be described as a link between physical and distributed systems that are individually defined. Using communication tools and devices, machines can interact to achieve given targets, focus on embedding intelligent sensors in real-world environments and processes. The Industrial Internet of Things (IIoT) relies on both smart objects and smart networks and also enables physical objects integration to the network in manufacturing and service processes.

MACHINE-TO-MACHINE COMMUNICATION (M2M)

M2M, central to the shop-floor, impacts Industry 4.0 and refers to technologies allowing for the automated exchange of information between the CPS, which constitutes the Industry 4.0 production environment. M2M can be considered as the integral technology of the 'Internet of Things' (IoT). Through advanced embedded sensor and actuator applications technology, the entire production floor can rely meaningful information, forming the interface between the physical and the virtual worlds. This provides a level of transparency that enables huge improvements in manufacturing, from performance management to entire new business models. While the most evident usage forms of M2M will be in intra-company linking of production assets, M2M is also the key enabler when it comes to cross-company operations.

Considering manufacturing advancements supported by communication and networking technologies, manufacturing industries are ready to improve the production processes with big data analytics to take the advantage of higher compute performance with open standards and achieve the availability of industry know-how in advance. As a result of the penetration of manufacturing intelligence, manufacturers can be able to enhance quality and increase manufacturing output.

RFID technologies: The RFID method is considered to be the successor of Optical Mark Recognition (OMR), one of the most recognizable and most frequently used AutoID methods, especially in the area of bar codes applications. The RFID technology is used in many areas of the economy. The most commonly used applications of RFID technology of the serious business importance include:

- **Logistics**
- **Pharmacy**
- **Airports**
- **Libraries**
- **Food Industry**

Smart Factory has some critical operations such as smart logistics, transportation, and storage by satisfying efficient coordination of embedded systems and information logistics. These operations include identification, location detection, and condition monitoring of objects and resources within the organization and across the company using Auto-ID technologies. The application of RFID technology allows achieving the highest level of the supervision of goods' flows throughout the supply chain (traceability). The accurate tracking of the path of goods is possible by collecting information in each element of the supply chain from the producer, through wholesalers and distributors up to retailers. It allows optimizing the supply process, to eliminate all errors and shortcomings, such as unjustified retention of goods, losses, and thefts, etc. The information about present locations of specific production batches is extremely essential from the point of view of some industry branches.

CYBER SECURITY

As mentioned in previous sections, the Industry 4.0 transformation requires intensive data gathering and processing activities. Integrating IoT devices and cyber security technology in the communications networks of critical infrastructure implies major ethical aspects that humans should be able to sense and understand, while benefiting from maximum possible levels of trust and privacy. This concern is represented by the need for different IoT verticals to develop reliable cyber security frameworks to prevent abuse from malicious interventions, including those originated by organised crime, terror organisations, or state-sponsored aggressors.

SENSORS AND ACTUATORS

Everything is getting smarter and data generated at all levels of the production process are used to improve product quality, flexibility, and productivity. This would not be possible without smart sensors, which generate the data and allow further functionality from self-monitoring and self-configuration to condition monitoring of complex processes. In analogy to Industry 4.0, the development of sensors has undergone distinctive stages culminating in today’s smart sensors or "Sensor 4.0". Sensors and actuators are the basic technology for embedded systems as the entire system obtains a control unit, usually one or more microcontroller(s), which monitors(s) the sensors and actuators that are necessary to interact with the real world.

Sensors and instrumentation are central driving forces for innovation, not only for Industry 4.0, but also for other megatrends that are described with the adjective smart, e.g. smart factory, smart production, smart mobility, smart home, or smart city. Intelligent decisions of complex systems are based on the knowledge of the system as well as ambient conditions and influence factors provided with high accuracy by sensors.

ADVANCED ROBOTICS

Producers are now deploying advanced robotics as an essential element of advanced automation that enables the self-controlled factory of the future. Enhancing plant structures and processes with digital technologies can increase productivity and flexibility in both the factory and the supply chain, enabling producers to rapidly adjust to changing customer needs.

Advanced robotics is a key element in the movement toward advanced automation, which is helping to dramatically improve factory operations. What makes automation "advanced"? The defining characteristic is decentralized intelligence that allows devices and equipment to make decisions and take actions autonomously, without human intervention. This autonomy provides the underpinning for self-controlled operations in the factory of the future. Advanced automation consists of four building blocks (BCG Küpper, D. et al., 2019):

- **Holistic Data Models.** A holistic data model (also known as a digital twin) consists of a digital representation of products and the production system along with their life cycles. It permits virtual commissioning of production systems, including equipment setup and integration, through simulation technologies. Production equipment (such as advanced robots) can access the models to, for instance, plan the required path on the fly.

- **Cloud-Edge Infrastructure.** Cloud-edge infrastructure shifts computational power and storage to the production network's edges, thereby bridging the domains of IT and operations technology. Such infrastructure is more effective than traditional IT infrastructure at helping producers overcome such challenges as data latency, limited bandwidth, and intermittent connectivity on the shop floor. It allows producers to collect data and transfer it to cloud services for processing. Also, it enables processes on the shop floor to adjust autonomously to environmental changes.

- **Data-Processing Technologies.** If it is to be converted into meaningful information, data of different sizes, velocities, and shapes ranging from transactional objects (such as images) to Internet of Things data requires timely processing. Recent advances in data processing technologies allow producers to continuously optimize processes (such as path planning).

- **Workflow Control System.** A workflow control system synchronizes all tasks that equipment or human workers perform in manufacturing and logistics processes. It is the backbone of machine-dominated system configurations. Efficient management of the entire workflow requires the digital connection or integration of both machines and human workers. Workflow control system configurations are likely to evolve from centralized architectures into decentralized ones.

Since advanced robots can self-adjust based on environmental perception, they can perform complex assembly processes, such as those involving flexible parts. Direct, real-time communication between work pieces and robots—for example, by using radio-frequency identification technology—also supports assembly. For example, robots can quickly change tools as needed, without requiring explicit prior instruction.

New design technologies, additive manufacturing, and cloud-edge technologies open up new opportunities to create autonomous, decentralized production processes. Additive-manufacturing technologies are used to produce parts, which an advanced robot then picks up and moves. Because the robot's path of movement is based solely on the relevant data models of products, processes, and equipment, there is no need for manual intervention.

Advanced robotics will have a major effect on the workforce. Jobs that primarily involve routine manual activities (such as loading and unloading machines) are the likeliest to be fully automated.

4 Qualification Research in the Context of Industry 4.0

The issue of vocational and academic qualification remains a central innovation topic and retains a strategic importance.

The vocational and academic training system is well equipped, its structure allows a dynamic adaptation of existing job profiles. However, new content, qualifications, and job profiles that are of importance to the industry as a whole may need to be identified more quickly in the coming years than has been the case to date. Given the diversity of technologies and possible business model innovations and the expected dynamics, the requirements here are increasing.

The assessments of the development of qualification in the context of Industry 4.0 differ. Three variants are apparent. One assumes polarisation, others expect generally an increasing need for qualifications, and a third group sees dual vocational training as an increasingly important link between different qualification levels. (Sabine Pfeiffer, Horan Lee, Christopher Zirnig, Anne Suphan, 2016).

Commercial technical training occupations play a central role in terms of quantity. The classic metal and machining jobs and the hybrid job of mechatronics dominate. The young job description of the production technologist has so far hardly been accepted. The content of the profile is not well known.

Qualification research, which combines technological description criteria of Industry 4.0 and competence-oriented expectations of specialists, should clarify the question of which competencies I4.0-specialists require and will still be necessary for specific activities in production in the future or cannot be efficiently automated in the future.

Cyber-physical social systems (CPSS) tend to integrate computation with physical processes as well as human and social characteristics. The fusion of cyber, physical, and socio spaces through Industry 4.0 emerges new types of production systems known as cyber-physical production systems (CPPS). CPPS enriches communications among cyber-physical-socio space in the production environment. Utilizing human-centered CPPS in smart factories results in a mutual transition from human-machine cooperation to active collaboration, which is characterized by cyber-physical-socio interactions, knowledge exchange, and reciprocal learning (Ansari F., Khobreh M., Seidenberg U., Sihn W., 2018).

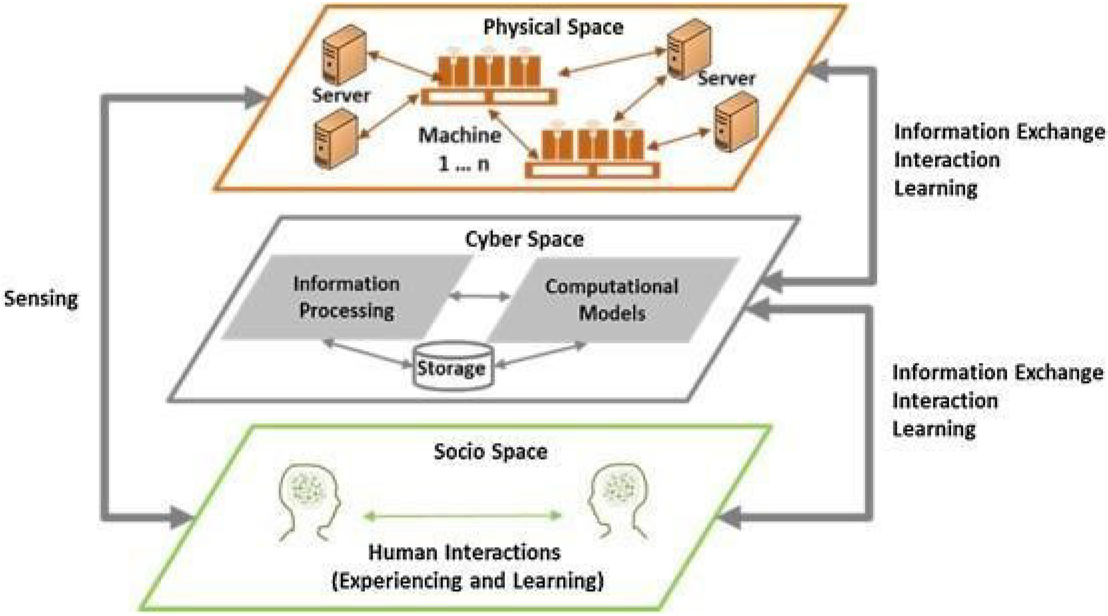

Figure 3: A problem-solving ontology for human-centered cyber-physical production systems (Fazel Ansari, Marjan Khobreh, Ulrich Seidenberg, Wilfried Sihn)

The world-of-work in I4.0 is asking for graduates that are interdisciplinary-educated and practice-oriented. Some institutions already meet these expectations, using learning factories for realistic, action-oriented classes and training. Lecturers are confronted with the challenge to identify future job profiles and correlated qualification requirements, especially regarding the conceptualization and implementation of CPPS, and to adapt and enhance their education concepts and methods adequately and consequently. For the new, virtual world of advanced manufacturing, a proper understanding of engineering as well as computer sciences is essential. Industry 4.0 implies this interdisciplinary split. Integrated competencies for product and process planning and design, methodological competencies for systematic idea and innovation management as well as a holistic system and interface competence will be crucial to achieving interconnection of physical and digital processes and machines.

HOW?

The "how?" encompasses the question of the design of job profiles as well as the demonstration of concrete didactic consequences, e.g. the development of models for competence development and diagnosis, strategies for curriculum development and design, concepts in training and further education as well as teaching and examination concepts.

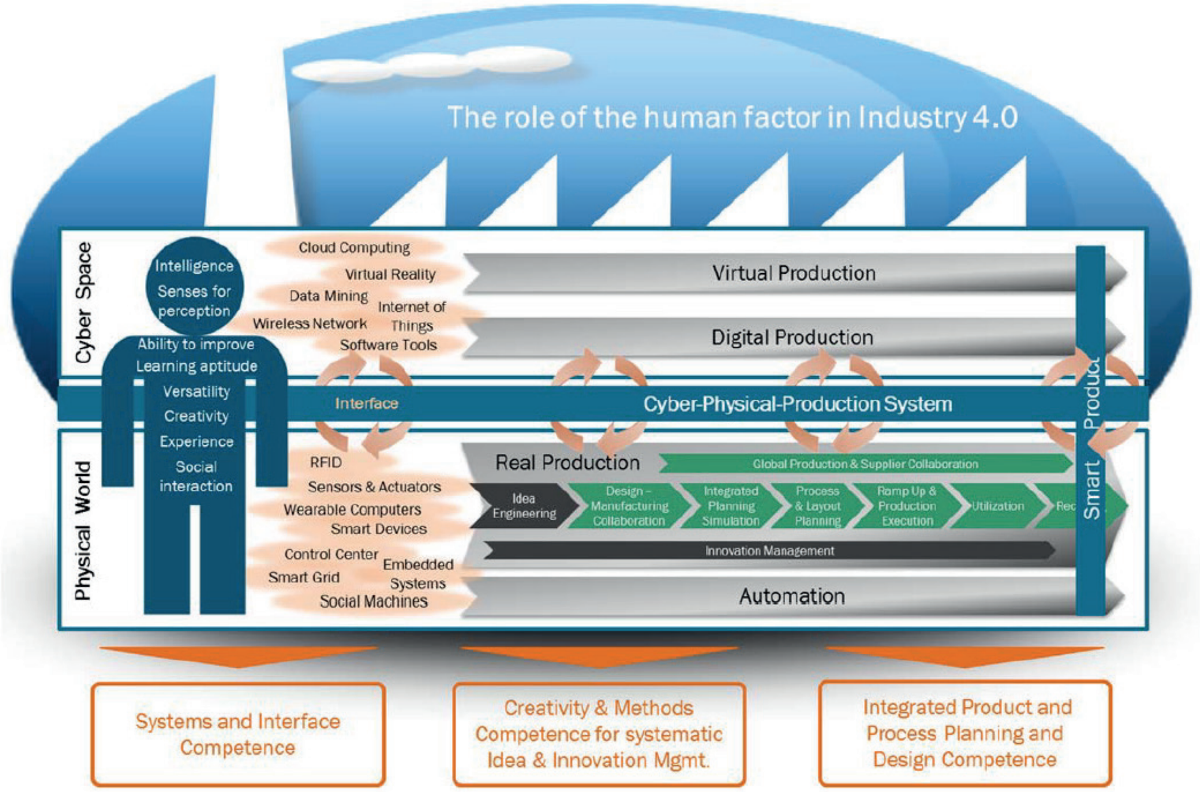

Figure 4: The role of the human factor in industry 4.0 (Vienna University of Technology and the ESB Reutlingen)

T-SHAPED PROFESSIONALS

Across all sectors of Industry 4.0, the new digital millennium requires new types of professionals and work practices. To help learners be successful in this dynamic environment of rapidly changing smart service systems, education systems of the future should encourage hyper-specialization, hyper-flexibility, or the development of T-shaped digital professionals and citizens—future-ready innovators who uniquely combine specialization (critical thinking and problem-solving depth) and flexibility (empathy, breadth of knowledge, skills, experience, and complex communication abilities) and who also use smart machines as assistants.

There are I-shaped, T-shaped, H-shaped, Pi-shaped, and Dash-shaped professionals (see Figure 5). The shape of a professional is used to describe whether he or she is a deep specialist in one area ("I-shaped"); deep specialist in two areas ("Pi-shaped" or "H-shaped"); deep in just one area but with good knowledge, skills, experience, and complex communication abilities across many other areas ("T-shaped"), with practicality (practical relevance); or not deep but with good breadth—a generalist ("Dash-shaped").

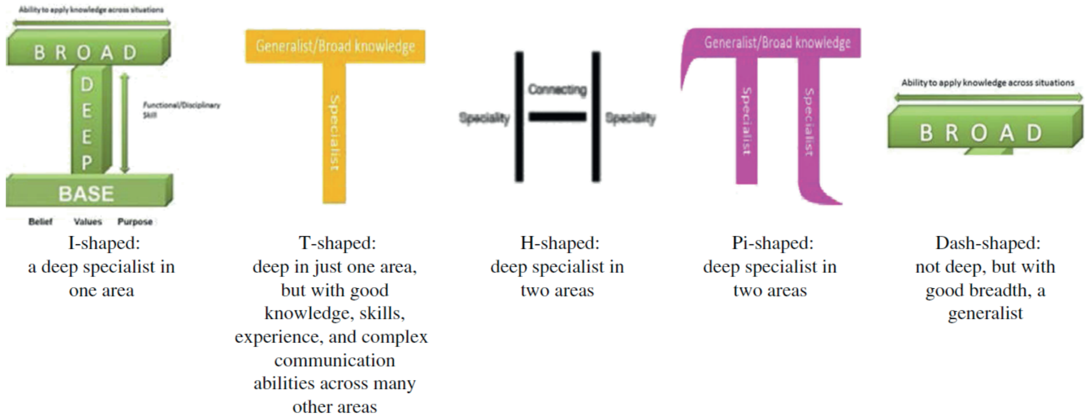

Figure 5: Different shapes of professionals (Haluk Demirkan & James C. Spohrer, 2018).

The earliest known use of the phrase "T-shaped people" in print was in a 1991 London newspaper editorial. David Guest wrote that T-shaped people are "a variation on Renaissance Man, equally comfortable with information systems, modern management techniques, and the 12-tone scale" (Guest 1991). T-shaped professionals combine the benefits of functional/technical skills and deep problem-solving competencies in one area with broad complex social skills e.g. communicative and cooperative abilities and skills across many areas. They can work in an interdisciplinary agile fashion and to see how different ideas, areas, people, and processes connect (Haluk Demirkan & James C. Spohrer, 2018).

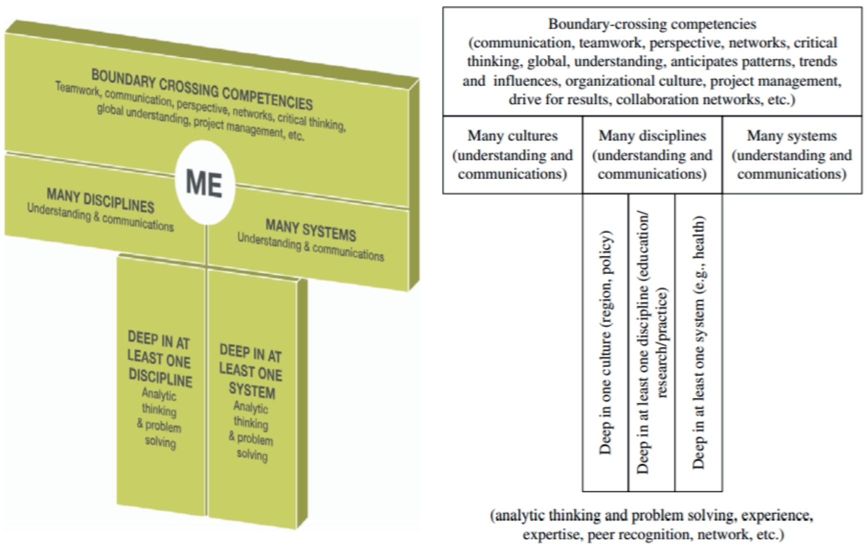

Figure 6: T-Shaped Model (Haluk Demirkan & James C. Spohrer, 2018).

Demirkan and Spohrer (2018) state that PHE institutions are training professionals to remain siloed (I-shaped) into functional disciplines and functional organizations that are not appropriate for today's challenges and process-oriented organizations (see also chapter .. St.Gallen model). This is problematic as graduates focusing on Industry 4.0 will be confronted with exponential surges in information and data management, the pressure to become more inter-and transdisciplinary, and increasing demands to function in a collaborative and interconnected business world. T-shaped curricula require helping learners connect with multidisciplinary teams and problems that simulate future work contexts. Learning is powerful when students apply theoretical principles to real-life cases in conjunction with students from other disciplines.

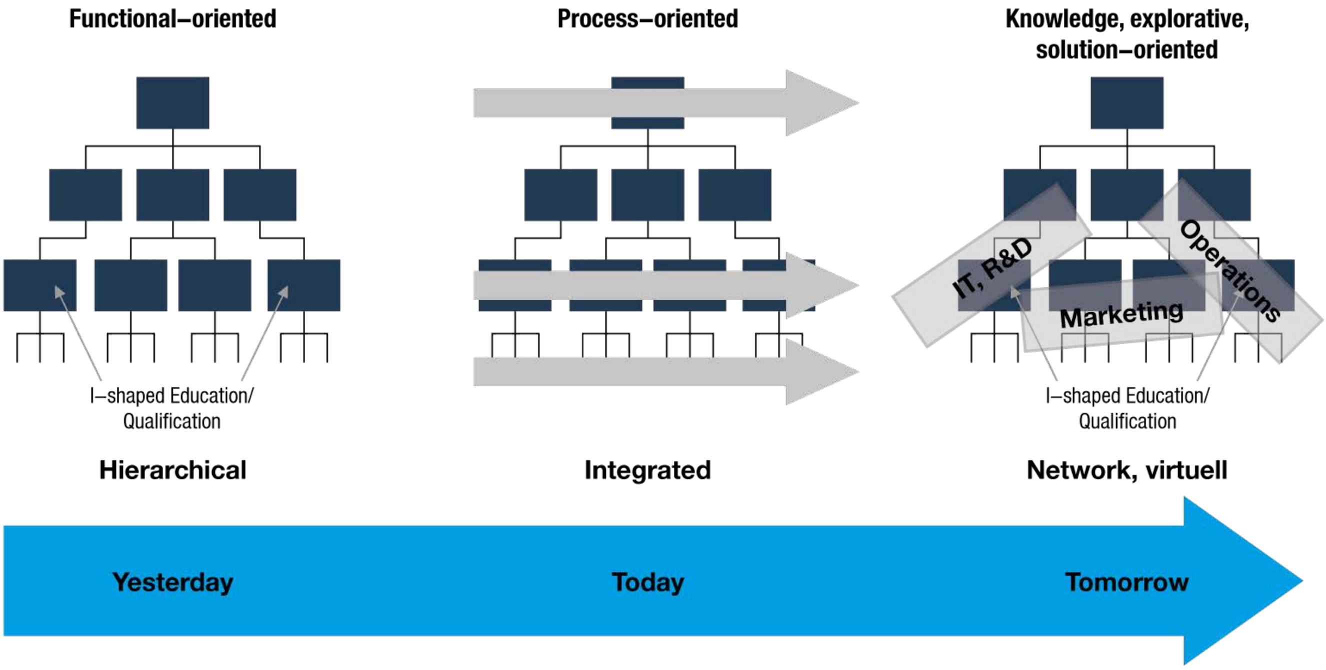

Figure 7: Organisational transformation (DHBW own illustration)

To develop and train students to become innovative T-shaped professionals, education needs to integrate multidisciplinary courses, to have more interaction with businesses, and to have partnerships with the world of –work e.g. through dual education models. Courses need to rapidly evolve to benefit from new knowledge (discovery, research) and new applications (engagement, entrepreneurship, innovation) through work-based learning and teaching in labs or learning factories. The students in this multidisciplinary curriculum will have a breadth of knowledge across the disciplines and depth of knowledge within at least one of the many disciplines.

KEY NEEDS IN TERMS OF EDUCATION

The concept of I4.0 together with Education 4.0 brings significant innovation for the industry, schools, and higher education institutions. To adequately and timely respond to the need of equipping students with suitable qualifications, skills, and competencies the education institutions should adopt and the effects of the related changes will be significant, and required to be carefully developed and implemented.

There are two conflicting development paths concerning the interaction of humans and machines in the discussion, having a direct impact on I4.0 qualification and competency development:

- **The specialization scenario or "assistant-tool scenario"**

- **The "automation scenario"**

The specialization scenario or "assistant-tool scenario"

The new technology is primarily seen as an opportunity to support employees. It serves as the basis for decisions, because the networked objects provide the necessary information. Digital technology is used as a tool. The focus of the activities of production workers is the control, monitoring, and regulation of complex systems. Humans remain the leading decision-making body (Holtgrewe, 2015).

The "automation scenario"

Here, too, the technology processes and distributes the information in real-time. In this scenario, however, the control and control tasks are mainly solved technically by self-controlling, decentralized production resources. Digital technology decides, controls, directs, and controls. The employees primarily carry out executive tasks.

The so-called hybrid scenario, in which the dualism between humans and technology is broken up in favor of new forms of interaction and cooperation in management and control tasks, the type and quality of the requirements will ultimately depend on the specific layout of the work organization and interfaces to technology and human actors (Ahrens & Spöttl, 2018).

If one understands new production systems as socio-technical systems, e.g. if it is considered that technical innovations are integrated into organizational processes and these, in turn, into social processes, then there are different design options and scope for Industry 4.0 and it is not just about the need for adjustment in terms of education.

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To increase the success rate of the I4.0 concept in practice, it is important that the supply-side actors must continue to focus on work-based learning and training, as well as help establish users groups and networks that can foster organizational learning about I4.0 success and failure factors. Dual training models - also in the tertiary sector - may meet the new and broad requirements in the course of Industry 4.0 better than purely educational institutions.

21st-century skills encompass not only technical/engineering and domain-specific knowledge and expertise, but also domain-independent meta-skills such as critical thinking, creativity, communication, and cross-cultural collaboration, and moreover dealing with the complexity of future industrial issues of Industry 4.0.

Therefore fundamentals of I4.0 and the associated technologies must be taught within the VET schools and HVET institutions and new curriculums should be developed and applied for new programmes and apprenticeships. Applying Education 4.0 in Advanced Manufacturing Education leads to learning factory 4.0 as shown in figure 8 (D. Mourtzis, 2018).

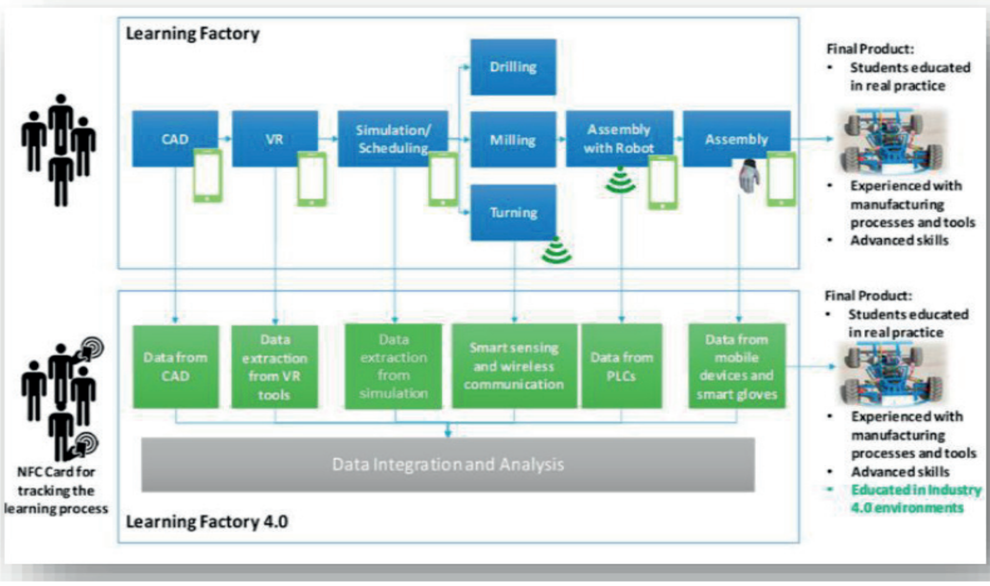

Figure 8: Implementation of Learning Factory 4.0 (Applying Industry 4.0 and Education 4.0 to Engineering Education); Irina Neaga, 2019

The learning factory aims at incorporating the learning and working environment from which realistic and relevant learning experiences arise. The learning factory follows a two-way knowledge transfer channel (i.e., factory-to-classroom and lab-to-factory) in which manufacturing topics are the basis for new synergy models between academia and industry.

KEY AREAS OF MISMATCH IN ADVANCED MANUFACTURING

Manufacturing itself faces rapid advances in production-related technologies, tools, and techniques. Manufacturing teaching and training have to keep pace with the advances in manufacturing technology and with the demands from the labour market. The current practice is deficient in providing manufacturing employees with a continuous delivery of engineering competencies and a strong multi-disciplinary educational and training background. Traditional teaching methods show limited effectiveness in developing employees' and students' competencies for current and future manufacturing environments. Besides, the lack of soft skills has been widely recognized by employers. Modern concepts of training, industrial learning, and knowledge transfer schemes are required that can contribute to improving the performance of Advanced Manufacturing. These new concepts need to take into account that:

- **Manufacturing as a subject cannot be treated efficiently in a classroom alone**
- **Industry can only evolve through the adoption and implementation of new research results in industrial operation**

More specifically, new learning approaches are needed to:

- **Allow training in realistic manufacturing environments**
- **Modernize the learning process and bring it closer to the industrial practice**
- **Leverage industrial practice through the adoption of new manufacturing knowledge and technology**
- **Increase innovation in manufacturing by improving the capabilities of young engineers, e.g. problem solving, creativity, and systems thinking capabilities.**

In the last years, learning factories as close-to-industry environments for education and research have proven to be an effective concept addressing these challenges.

The activity profiles and as a consequence the qualification, competency, and curriculum development will come under strong pressure to change, due to two trends:

On the one hand, conventional production processes with a strong division of labour will be embedded in a changed organizational structure and workflow and will be enriched with decision-making, coordination, control, and accompanying service functions.

On the other hand, the interaction of virtual and real machines, plant controls, and production management systems must be organized and coordinated.

The ability to act in a self-directed and self-organized manner is playing an increasingly important role in new forms of business and work organization. There are fewer and fewer concrete guidelines on how something should be carried out, and the precise planning is left to the workers themselves. People are challenged to find their way around in open and confusing, complex, and dynamic situations.

In summary: As ICT, production, and automation technology and software grow together, more work tasks will have to be mastered in a technologically, organizationally, and socially very broad field of action.

There is a dire need to identify and develop the disciplines and the required missing abilities in order to build suitable skills into the workforce of industry 4.0.

Higher education institutions (universities and technical colleges) play a censorious role in shaping the societal transitions requisite for industry 4.0 movements. However, today's higher education was developed in the context of the previous three industrial revolutions, which do not provide the necessary skills for shaping industry 4.0 movements. Also, most manufacturing and service industries will no longer demand for specialist personnel only but also the generalists.

6 Key Directions for Action in the World-of-work

Changes in qualification and job requirements - and indirectly partly the resulting qualification measures – result thus from the three socio-technical dimensions or their interfaces.

These interfaces have to be focused on because it is not about the respective design of the three individual socio-technical subsystems, but about the "interaction and the combination of the elements, hence technical-social configurations" (Vogel-Heuser, Birgit, Bauernhansl, Thomas, ten Hompel, Michael, 2018).

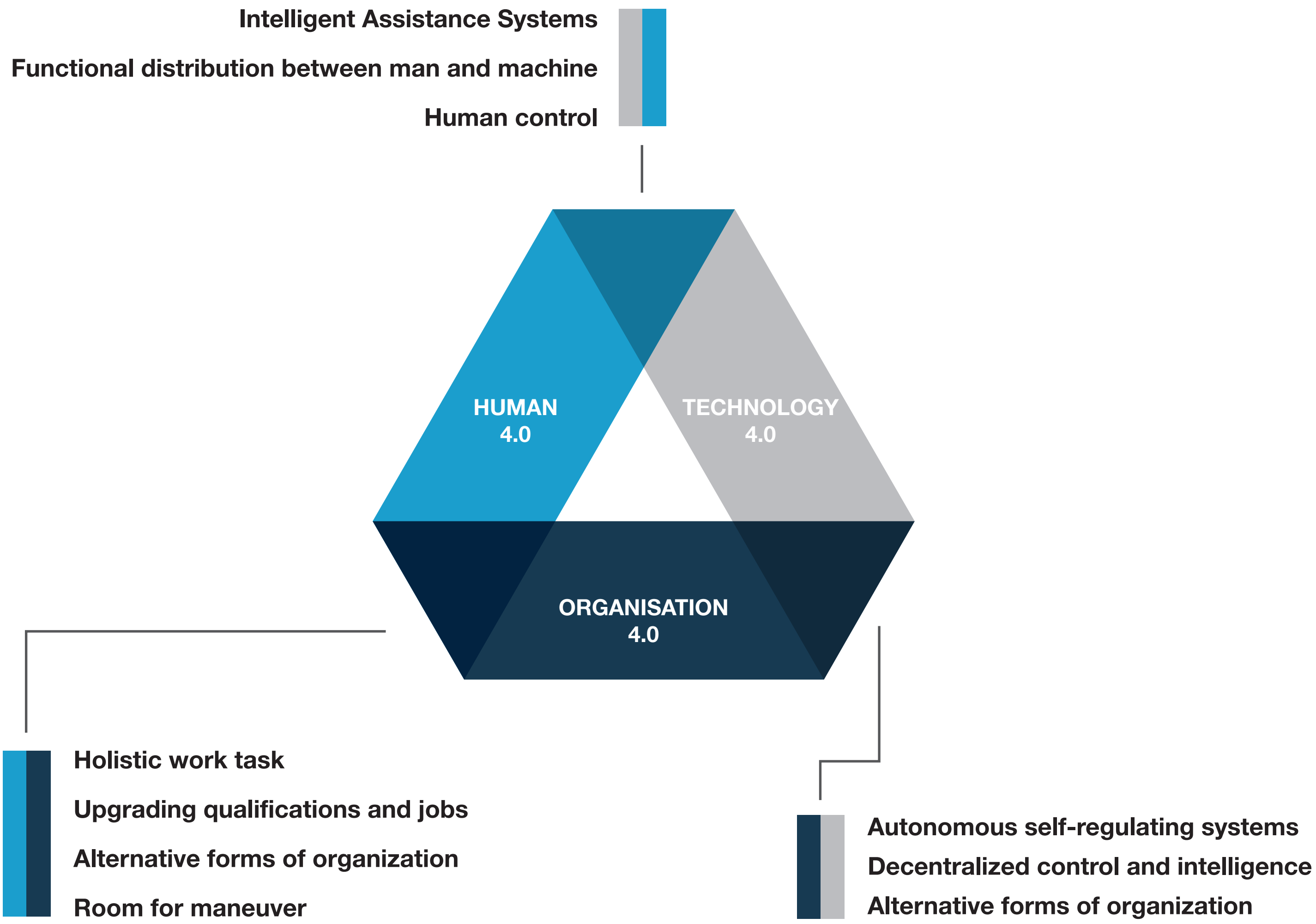

Figure 9: Hirsch-Kreinsen/ten Hompel 2016

Interface: Technology – Human

This interface is about answering the key question, how functions, tasks and decisions are distributed between machine and human and "to what extent employees can use the system directly, to control it and thus take over the responsibility for system operation."

Interface: Organisation – Human

This interface is ultimately not Industry 4.0-specific or due to digitization. From a normative perspective, it is about the general aim to design work tasks and job profiles, in order to be as holistic as possible, open up decision options and create learning opportunities.

Interface: Technology – Organization

The respective state-of-the-art processes in the company or the value chain have a major influence on the organization dimension. Understanding cross-functional and inter-company processes, as well as anticipating potential errors are essential requirements and skills settings. It is less about working in interdisciplinary teams (this is required by those involved in the development and implementation of the process infrastructure), but rather about the employee's thinking about other stakeholder's positions and processes.

The criterion -involvement in the existing or changing work organization - also indicates that the design of the interface between technology and organization is human-centered and not technology-determined.

7

Conclusion

Industry 4.0 describes a profound economic paradigm shift affecting both production and the business models changed over the long term. The fourth industrial revolution not only transforms production processes and the value chain, but also organizational forms and structures in companies as well as the competence and qualification requirements for employees.

A task-specific, but generally very well-founded, technical training is required as the basis of I4.0 qualifications. On the one hand, this technical basic knowledge has to be deepened in a specialist manner and, on the other hand, should be very broad in order to be able to deal with complex tasks and to be able to quickly analyze problems or new requirements. The technical breadth is also necessary because part of the potential for personal savings in connection with Industry 4.0 lies in being able to use one person at the same time for several machines or process steps.

However, learners with I4.0 qualifications are not only in demand for their specialist skills. Personal skills such as responsibility, self-regulation, organizational skills, initiative, and willingness to perform or methodological skills such as problem-solving skills, creativity techniques, or systematic design are required. Since I4.0 Advanced Manufacturing takes place in networked environments and will have a higher degree of interaction, social skills such as communication and conflict management skills as well as the ability to change perspectives are also required.

Concerning the qualification of workforces, it is important that existing offers in education and training are work-related about Industry 4.0 and to expand its content in the direction of digitization. New possibilities and modern concepts of training, industrial learning, and knowledge transfer schemes are required that can contribute to improving the performance of Advanced Manufacturing. This applies, especially to small and medium-sized companies to raise awareness of Industry 4.0 as well as to identify and develop the disciplines and the required missing abilities in order to build suitable skills into the workforce of industry 4.0.

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