EXAM 4.0

THE EXCELLENT ADVANCED MANUFACTURING 4.0

ENGLISH

The AM Workshop 4.0 Framework

Advanced manufacturing 4.0 LABs

04

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- Abstract

Industry 4.0 sets new demands on workers, new technologies require innovative solutions, thus innovative workers who can adapt to the required adjustments and provide value to the Industrial sector. The new demands on workers does in turn generate new requirements on education. Research regarding methods for development of Industry 4.0 education have been carried out by Curt Nicolin Gymnasiet and the EXAM 4.0 consortium partners because of the new requirements. EXAM 4.0 has produced reports that include definitions of requirements that a VET/HVET centre must fulfil to be able to provide students with key enabling skills and competencies that are crucial in the Advanced Manufacturing sector. This report includes information regarding teaching in Industry 4.0 and the responsibilities of people that are involved in the process. All work is also used to create a framework, describing the ideal process to implement when creating new AM LABs 4.0.

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- Abbreviation

AI= Artificial Intelligence

AM = Advanced Manufacturing

AR = Augmented Reality

CAD = Computer Aided Design

CAM = Computer Aided Manufacturing

CoVE = Centres of Vocational Excellence

CPS = Cyber-Physical systems

D = Deliverable

EQF = European Qualifications Framework

EXAM 4.0 = Excellent Advanced Manufacturing 4.0

HVET = Higher Vocational Education and Training

I4.0 = Industry 4.0

ICT = Information and communications technologies

IoT = Internet of Things

IIoT = Industrial Internet of Things

IT = Information Technology

KETs = Key Enabling Technologies

M2M = Machine to machine communication

OT = Operational Technology

RFID = Radio Frequency Identification

VET = Vocational Education and Training

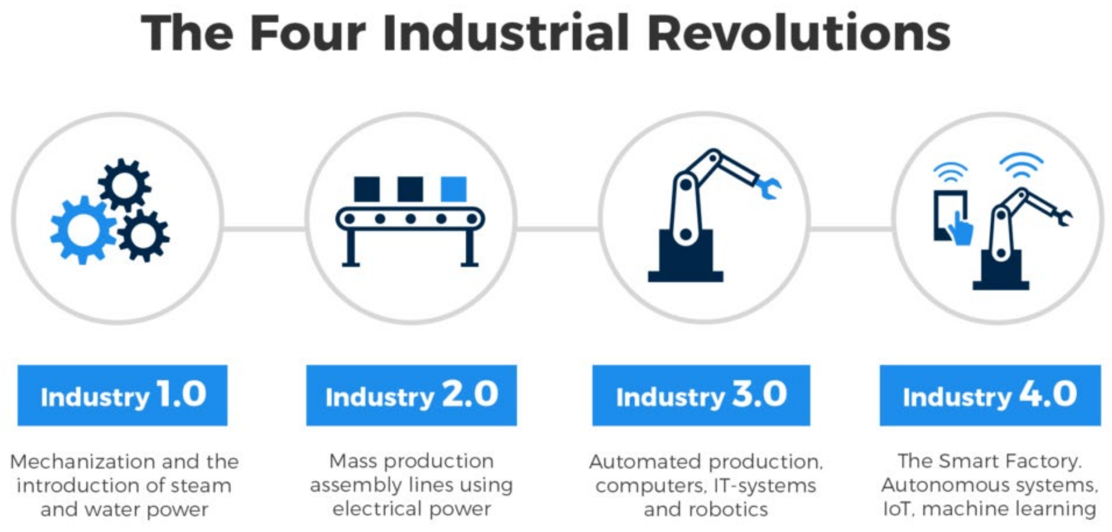
VR = Virtual Reality

- Introduction

The fourth section of the report includes graphics and characteristics of the diverse elements in the AM Workshop 4.0 Framework. Various graphics that give visual representations of important aspects of Industry 4.0 and involved technologies. Different learning approaches such as Challenge based Learning as one ideal methodology. Information regarding teaching in Industry 4.0 and roles and responsibilities of people involved. This section also includes recommendations on planning, programming, implementing and monitoring new AM LABs.

The AM Workshop 4.0 Framework

- **4.1 Industry 4.0**



We are currently in a transformation, the way of producing is changing due to digitalization. This transformation goes under the name Industry 4.0, or its acronym I4.0, and is the fourth industrial revolution. The transformation extends what was started in the third industrial revolution. Computers, automation, robotics merge with new technologies such as autonomous systems promoted by machine learning and data (Marr 2018). Interconnectivity, automation, machine learning, and real-time data are the key focus of Industry 4.0. The idea of I4.0 is merging physical production with Smart digital technologies to create well-connected ecosystems regarding manufacturing and supply chain management (Epicor n.d).

4.2 Characteristics of the AM Workshop 4.0 Framework

Defining or characterising advanced manufacturing workshops for VET centres requires a technological reference framework that synthesises the main characteristics that the digital transformation is generating.

The reference framework is based on the adaptations that are being carried out in companies, the way that companies related to advanced manufacturing are integrating and implementing the transformation towards smart factories.

It is important to remember that we are talking about teaching and learning environments, where the implementation of technology is directly associated with the competences that are educated and the learning results that are to be achieved.

Following the widely used levels and elements of the automation pyramid shown in figure 16 and including some other elements, we can visualize a learning system built following a similar architecture.

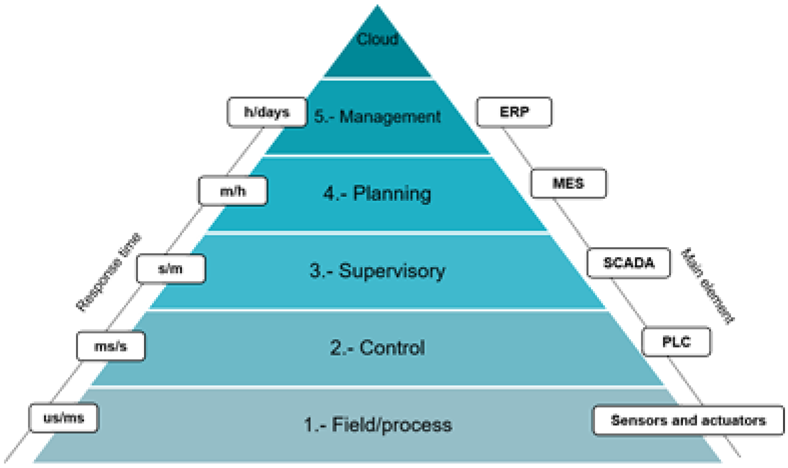


Figure 16 *Automation pyramid* (EXAM4.0)

A simplified representation of the potential structure of a LAB for VET training is shown in figure 17. The proposed LABs should be digitalized to a representative level that makes it possible to apply numerous of the digital features that potentially could be operational in Smart factories. Following the typical layers of an automated production line, the proposed AM LABs for VET would be configured around a production process. As this architecture is designed for learning purposes, the configuration would be open, modular and flexible.

Graphics and characteristics of the diverse elements of Industry 4.0 relevant to the AM Workshop 4.0.

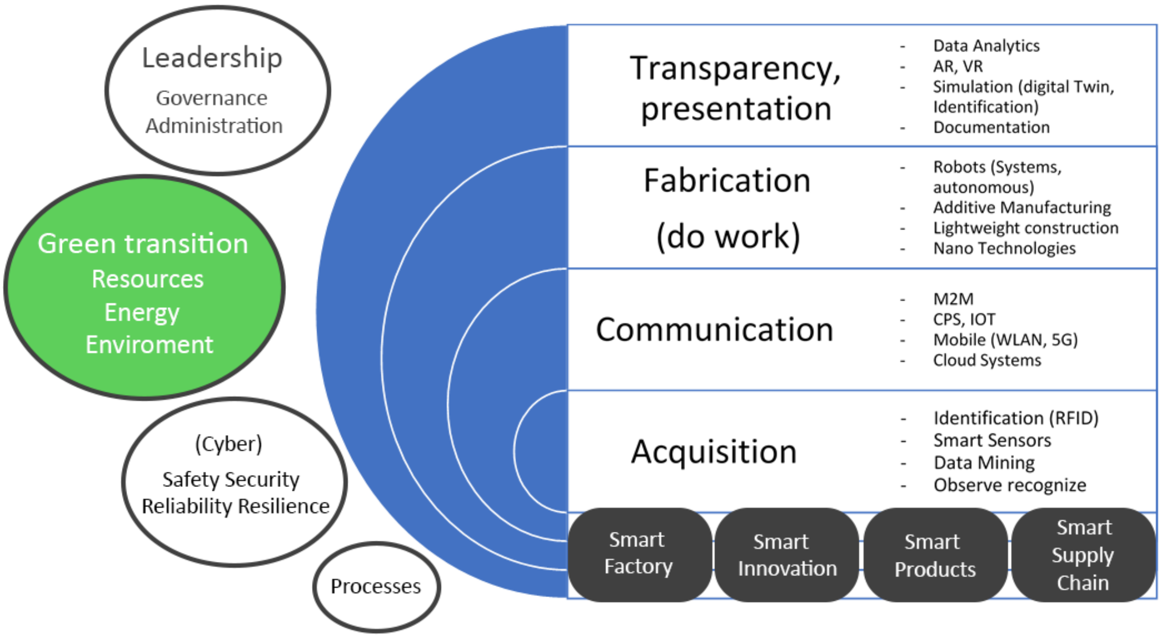


Figure 17 Configuration of an AM lab for VET (EXAM 4.0)

The first field level is the acquisition level. Second is the communication layer, where different communication protocols and systems would be implemented, not only linking and controlling all the field elements but also communicating with different machines and equipment. Third is the "fabrication layer" where the production takes place. The configuration and layout of the production machines, with learning purposes, would assure the appropriate production workflow. Complementary technology would be implemented: robots and cobots, additive manufacturing, line metrology, traceability etc. The fourth layer is the transparency presentation regarding.

Note that this representation is complementary to the *automation pyramid* shown in figure 16. The AM LABs for VET must contain the control levels, scada systems, MES systems and even ERPs to link the data from LABs with other digitized areas of the VET centres.

Driving Business models

Another relevant aspect to consider is the business model that drives the activities in industry. In an earlier EXAM 4.0 report we described the main drivers that will operate in different industries. Smart Solutions, Smart Innovation, Smart Supply Chains and Smart Factories are fields in which manufacturers will realize enormous potentials by digitizing their business. While Smart Solutions and Innovations primarily leverage company growth, Smart Supply Chains and Factories mainly drive efficiency.

Depending on the main driver used, all the operational models will vary, including the main technology enablers acting on the process. It is important to consider how it will affect the business models on the operative model in our AM LABs for VET. In figure 18 the main technology enablers acting depending on the driving business model are shown.

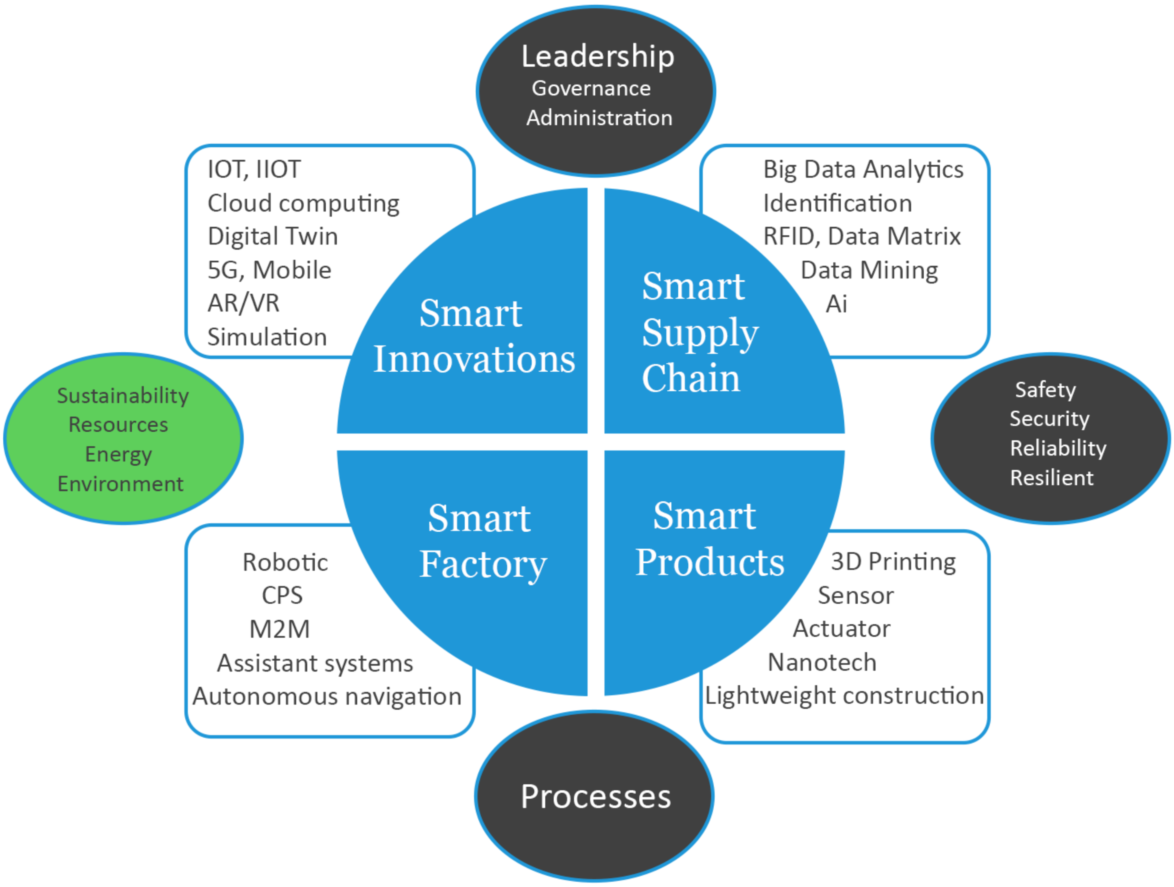


Figure 18 *Main technology enablers and I4.0 elements acting depending the driving business model* (EXAM 4.0)

This model gives a general picture of technologies, methods and elements important to succeed within I4.0.

In the following paragraphs, details about the four main business models are given:

Smart factory:

"The Smart Factory is a concept for expressing the end goal of digitization in manufacturing" (Koo 2020).

The term Smart Factory is most often used in relation with highly digitalized factories. These factories uninterruptedly collect production data and share data among connected machines and devices. Devices use the data for self-optimizing and the organization can use it to address problems within the factory in order to enhance the production. Numerous technologies are used within Smart factories to make it functional, for instance AI, Big Data Analytics, Cloud Computing, and IIoT. (Koo 2020).

Smart supply chains:

Industry 4.0 includes more than just Smart factories and implementation of technologies. Logistics 4.0 and Smart supply chain management concerns a variety of features regarding end-to-end logistics and supply chain management in Industry 4.0, such as IoT, CPS and advanced data analytics. (i-SCOOP n.d).

Smart factories use technologies such as sensors implemented in equipment that are connected to the IoT, together with numerous other advanced technologies like cyber-physical systems, data analytics, robotics and AI. These technologies play a key role in the management of smart supply chains.

Smart supply chain management has numerous benefits, such as predicting bottlenecks. The supply chain can be self-organizing and self-optimizing because of real-time data from sensors in the factory. Smart systems used in Smart supply chain management can predict future bottlenecks and support the implementation of lean production (Throughput 2019).

Smart products:

Concepts of Industry 4.0 like Smart factories and advanced manufacturing technologies drive innovation and development that affects both processes and products, this allows the creation of Smart products. (Schmidt et al. 2015, referenced in Nunes et al. 2017)

The concept "Smart" has no real definition, but the term usually refers to devices that independently cooperate with other devices in a network and with embedded systems carries out actions based on real-time updates (Raji 1994, referenced in Nunes et al. 2017). The development of Smart products and processes are of focus in the fourth industrial revolution, the developments are driven by the transformation from conventional factories to Smart factories (Radziwon 2014, referenced in Nunes et al. 2017). Smart factories have the possibility to control complexity and improve the production efficiency. A smart factory is defined by its intercommunication in networks with human resources, machines and equipment such as Smart products (Kagermann 2013, referenced in Nunes et al. 2017).

Smart products are important for I4.0 manufacturing, these products are implemented in the entire process of manufacturing and constantly support it and self-control particular parts of the production autonomously. Smart products are also informed about the parameters and future usage of themselves and will therefore provide status information regarding themselves throughout their lifecycle (Kagermann 2013, referenced in Nunes et al. 2017). The main purpose of Smart products is their interaction with the environment through computation, data storage and communication. Smart products can throughout their value chain give information regarding their progress, store information regarding earlier process steps and provide information about future production and maintenance processes as well. Smart products can also interact with physical environments without human involvement (Schmidt et al. 2015, referenced in Nunes et al. 2017).

Smart innovations:

The digitalisation of industry will not only transform value-creation processes but also give rise to new business models and new innovations. Smart, digital production processes present great opportunities for businesses – particularly for SMEs. New impulses come from a multitude of sources outside the own organization, and they must be proactively integrated into an open innovation process. However, in an interconnected Industry 4.0, ideas are much more valuable if they are embedded in an equally innovative periphery of devices or related solutions. Extended Innovation embraces the creation and distribution of ideas across organizational borders, whereas Connected Lifecycle Innovation leverages product lifecycle data as a source for innovation. Extended Innovation requires opening up innovation processes in manufacturing companies to external partners and customers. Communication and connectivity allow for cross-company innovation activities. Extended Innovation is a two-way exchange, with information flowing into and out of the company. While outside stimuli are actively brought into the company, it acts as a hub for then feeding them into the partner network to broadly support innovation and idea generation. Collaboration in the innovation process with both customers and partners will reduce the time-to-market and drive innovation speed towards a constant flow. Finally, innovations will become more sustainable by sharing information throughout the manufacturer's ecosystem. Connected Lifecycle Innovation differs from 'ordinary' product lifecycle management in its holistic approach: product-related information is coupled with other relevant data, such as machine parameters or customer order data. It is then analysed, processed and put to use for generating innovation, enabling data-driven R&D decision-making and business process innovation throughout the entire organization, such as in sales processes. Like Extended Innovation, Connected Lifecycle Innovation will lead to an increase of innovation frequency. It will reduce the time-to-market, implying growth potential as well as improved efficiency in operations, with decreased R&D cost.

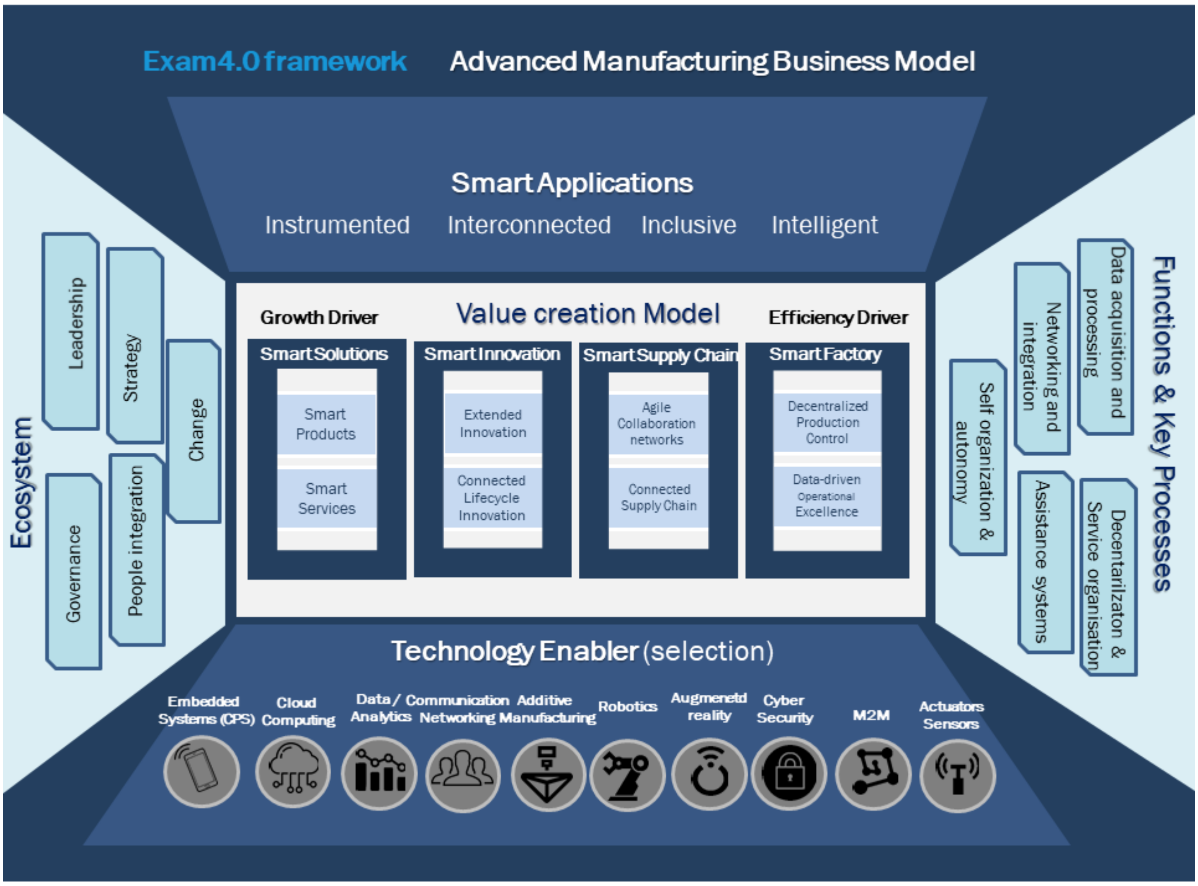


Figure 19 *EXAM 4.0 Manufacturing Business Model* (EXAM 4.0)

EXAM 4.0 LABs should agree with / or be based on the Exam 4.0 Framework and Exam 4.0 Competency framework written in an earlier EXAM 4.0 report.

The semi-structured questionnaire carried out by the partners of the consortium can be used not only when describing existing LABs but also when describing new EXAM 4.0 LABs.

- ### 4.3 Number of technologies

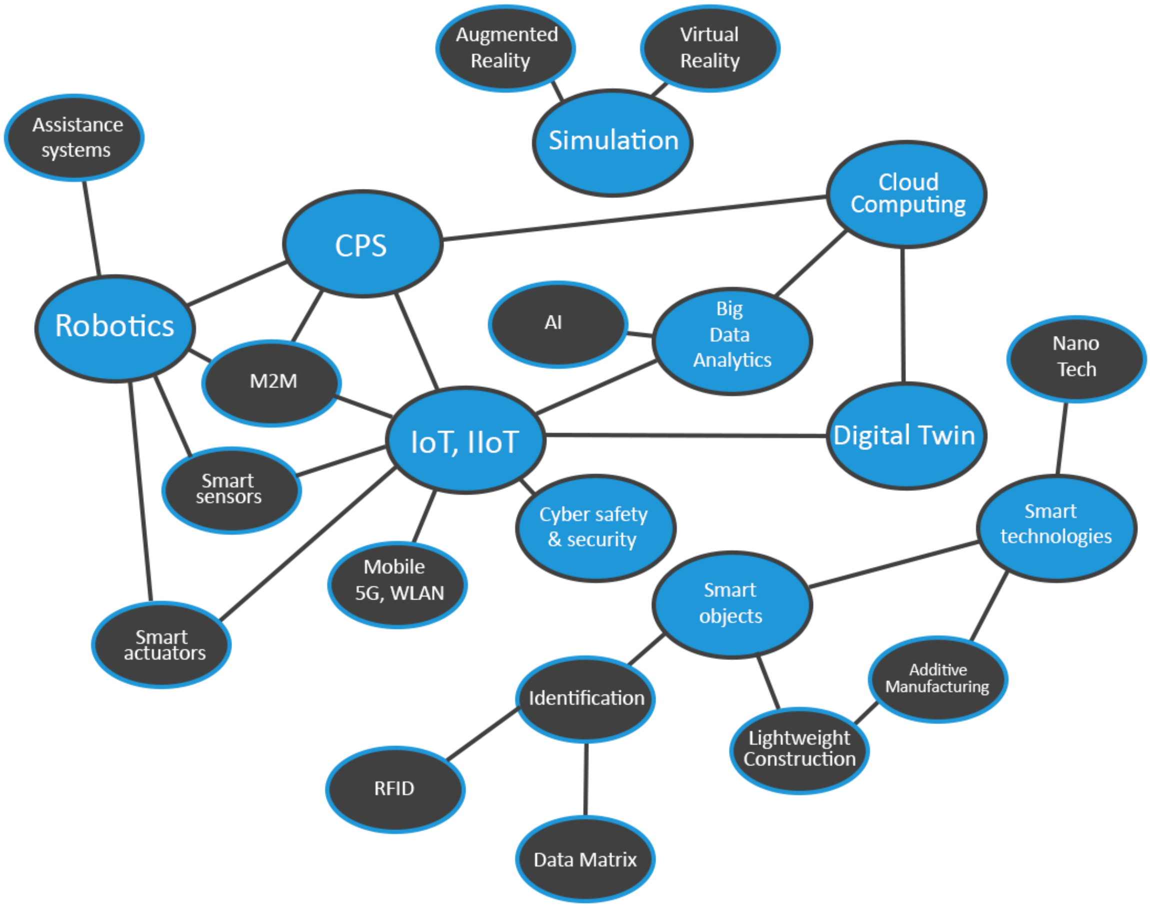


Figure 20 *Graphics of Advanced Manufacturing technologies* (EXAM 4.0)

The KETs and Industry 4.0, advanced manufacturing, related technologies have been described in section 2 of this paper. Figure 20 is a graphic screening of the technologies and its relations to each other. The graphic is based on the PowerPoint "Framework EXAM 4.0, technology enablers" from an earlier EXAM 4.0 report. The grey and blue ellipses represent layers of the different technologies and the line between them shows the relation between these technologies in a fundamental way.

Additive Manufacturing / 3D-printing

Whatever term is used, additive manufacturing or 3D-printing is the definition of a manufacturing method where material is added layer by layer, based on a sliced CAD-model. Both terms are correct but should be used in different contexts. Additive Manufacturing is more often used in relation to industrial scale manufacturing or as a collective name for various 3D-printing methods. The term 3D-printing is preferably used by people who do not work within manufacturing or the engineering area (K3 Syspro n.d).

Additive Manufacturing creates products, as aforementioned, via adding material layer by layer, unlike traditional manufacturing methods where materials are subtracted from the raw material (Linke 2017).

Rapid Prototyping (RP), Direct Digital Manufacturing (DDM) are both used within Additive Manufacturing, by creating 3D-parts, particularly by storing and joining the products with proper polymers, ceramics, or metals.

3D-printing methods:

Additive Manufacturing for polymer:

Powder Bed Fusion (PBF) is an Additive Manufacturing method, often used at an industrial scale. PBF has two subset methods. Multi Jet Fusion (MJF) which fuses the materials with agent and energy. Tiny liquid drops are applied to the material and these increase or suppress the heat absorption of the powder. An infrared source fuses the powder to solid material later. The other method is Selective Laser Sintering (SLS), which fuses the powder material with a laser. The movable laser sinters the layers and solidifies the powder.

Material Extrusion (MEX) has two subset methods. Fused Deposition Modeling (FDM) is the method most people think of when they hear of 3D-printing, often in the form of small printers that fit into an office landscape. The filament is wired-shaped plastic, the printer has a nozzle that places the filament layer by layer. The other method is Arburg Plastic Freeforming which is similar to FDM but uses polymer granulate instead, adding plastic granulate layer by layer.

Material Jetting (MJT) uses multiple nozzles to apply droplets of photopolymer on the layers. The photopolymer is instantly cured by UV-light afterwards.

Vat Photopolymerization (VPP) uses a vat of liquid photopolymer resin (Loughborough University n.d). VPP has two subset methods called Stereo Lithography (SLA) and Direct Light Processing (DLP). SLA uses a movable laser beam that solidifies the photopolymer. DLP uses a projector to expose each layer, the exposed material is polymerized and solidified.

Additive Manufacturing for metal:

Powder Bed Fusion (PBF) for metal has two subset methods. Selective Laser Melting (SLM) which fuses the powder material with a laser. Electron Beam Melting (EBM) uses a movable electron beam to selectively melt the metal powder.

Direct Energy Deposition (DED) has three subset methods. Laser Engineering Net Shape (LENS) adds layers and melts them with a laser beam simultaneously. Metal Powder Application (MPA) uses cold contact welding, metal powder materials are applied in layers with very high kinetic energy. Wire and Arc Additive Manufacturing (WAAM) fuses metal wire with an electric arc in layers to create large metal structures.

Material Extrusion (MEX), Fused Deposition Modeling (FDM) uses wire shaped metal that also contains plastic as support structure. The material is added layer by layer via a nozzle unit, the finished part will be sintered afterwards.

Binder Jetting (BJT) uses many nozzles to selectively put tiny binder droplets on the metal powder. The droplets with binding agent join the powder into solid material. The finished part will be sintered afterwards.

Material Jetting (MJT), Nano Particle Jetting (NPJ) uses a metal particle solvent fluid to create layers by a nozzle unit. The solvent evaporates and the nanoparticles join together, the finished product is sintered afterwards.

Additive Manufacturing for other materials:

Material Extrusion (MEX) for composites uses a method called Continuous Filament Fabrication (CFF). The material is wire-shaped and is selectively added layer by layer.

MEX with pasty materials uses a method called Paste Extrusion Modeling (PEM). The method is very similar to CFF. The nozzle unit does however not rise to the same temperature in PEM.

Material Jetting (MJT) uses “Drop on Demand” to apply multiple droplets of heated wax layer by layer. The material solidifies to a 3D-object when the wax is cooled down.

Sheet Lamination (SHL) laminates composite or paper via Selective Deposition Lamination (SDL) / Laminated Object Manufacturing (LOM). The nozzle applies droplets that laminate the material.

(AM FIELD GUIDE COMPACT 2020).

Embedded Systems (Cyber physical infrastructure) and Mobile Technologies

Embedded systems, 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 with respect to innovative functionalities including computing and communication infrastructure (Zhong et al., 2017 referenced in State of the art of AM and HVET/VET in Europe, 2020).

Cloud Technologies

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 "available on-demand". Demand based manufacturing uses the collection of distributed manufacturing resources to create and operate reconfigurable cyber-physical manufacturing processes. The main purpose for this 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 referenced in State of the art of AM and HVET/VET in Europe, 2020).

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 at first hand, primarily by stimulating their vision and hearing. VR is used prominently in two different ways:

To create and enhance an imaginary reality for gaming and entertainment (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) (State of the art of AM and HVET/VET in Europe, 2020).

Augmented reality (AR) is a technology that layers computer-generated enhancements atop an existing reality in order 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. The application of AR in the industry domain is valuable since it greatly improves the communication in product design and production development: it helps to identify and avoid design errors in early stages of the development process, it reduces the number of physical prototypes and saves time and cost for enterprises. AR is considered as a useful 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, products 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. In training operations, users can find in AR a powerful solution to enhance their skills. In products inspection, controllers can notice any discrepancies of items using powerful and versatile AR systems. In building monitoring operations, AR highlights any error or deviation of a facility in a simple and intuitive manner (State of the art of AM and HVET/VET in Europe, 2020).

AR improves reliability and safety of robotic systems showing workers the intentions of robots, it reduces costs and improves performances of maintenance systems, it shows any discrepancies of products superimposing models on the real object precisely (State of the art of AM and HVET/VET in Europe, 2020)

Data Analytics (Big data) and Artificial Intelligence (AI)

The terms data analytics/science, machine learning, and artificial intelligence (AI) fall in the same domain and are connected to each other, they have specific applications and meaning. Data science and analytics focus 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. Machine Learning is a subsection of Artificial intelligence, it is systems that automatically can learn and improve from experience.

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

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, the 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 which is gathered during R&D, production, operations and maintenance processes is increasing at exponential speed (Zhong et al., 2017 referenced in State of the art of AM and HVET/VET in Europe, 2020).

Communication and Networking (Industrial Internet of Things IIoT)

The Internet of things (IoT) is the infrastructure of interconnection among objects. In manufacturing systems, each device is embedded with electronic software, sensors, and actuators. These systems are connected to Internet networks. The IoT 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 IoT 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 (State of the art of AM and HVET/VET in Europe, 2020).

From a communications perspective, IoT and CPS 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 have become the prerequisite for actually implementing industrial IoT (IIoT) and CPSs (State of the art of AM and HVET/VET in Europe, 2020).

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. 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 (State of the art of AM and HVET/VET in Europe, 2020).

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 constitute 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 relay 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 (State of the art of AM and HVET/VET in Europe, 2020).

Considering manufacturing advancements supported by communication and networking technologies, manufacturing industries are ready to improve the production processes with big data analytics to take advantage of higher computing 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 (State of the art of AM and HVET/VET in Europe, 2020).

RTLS and 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 an 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 company using Auto-ID technologies. The application of RFID technology allows the highest level of the supervision of goods' flows throughout the supply chain (traceability). The accurate tracing 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 theft, etc. The information about present locations of specific production batches is extremely essential for some industry branches (State of the art of AM and HVET/VET in Europe, 2020).

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 of different IoT verticals. IoT verticals have to develop reliable cyber security frameworks to prevent abuse from malicious interventions, including those originated by organised crime, terror organisations or state-sponsored aggressors (State of the art of AM and HVET/VET in Europe, 2020).

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 (State of the art of AM and HVET/VET in Europe, 2020).

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 (State of the art of AM and HVET/VET in Europe, 2020).

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 (Buchner et al., 2019 referenced in (State of the art of AM and HVET/VET in Europe, 2020):

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 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. This 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 them to cloud services for processing. In addition, 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 on the basis of 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. (State of the art of AM and HVET/VET in Europe, 2020)

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- ## 4.4 Methodologies for I4.0 learning

One of the characteristics of the Centres of Vocational Excellence (CoVE) given by the EU commission is that they adopt Student Centred learning approaches and active learning methods.

In the EXAM 4.0 context, active learning methods are used in I4.0 teaching and learning environments. Relevant learning methodologies and further information regarding these are described accordingly:

- **Problem-based learning**

PBL is an educational method used to learn concepts and principles. This educational method is opposite to direct presentation of facts and concepts. Complex real-world problems are applied in PBL in order to encourage the students' learning. Besides determined skills and competencies in the education programme PBL can endorse education of problem-solving abilities, communication skills and critical thinking skills. The learning method supports among other things life-long learning and teamwork (Duch, Groh, Allen 2001, referenced in University of Illinois Board of Trustees, et al 2020).

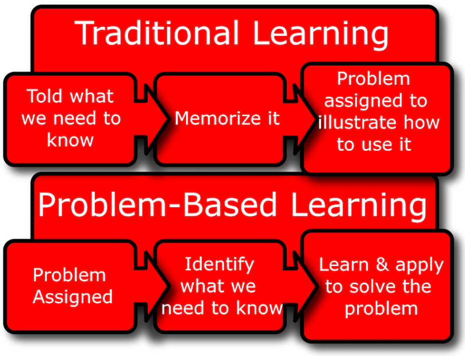

Figure 21 *Problem-Based Learning (PBL)* (Serhat 2020)

- **Project-based learning**

Project-based learning is an educational method where learners work with projects, the method involves real-world and meaningful tasks.

The project is performed under a specific time period, the timeline can be very varied. Project-based learning engages the students in solving real-world problems and complex questions. While students work with meaningful projects they indicate their skills- and knowledge-levels.

Students are improving content knowledge, additionally, critical thinking, collaboration, creativity and communication skills by using project-based learning as the educational approach (Buck Institute for Education n.d).

All of these are vital competencies for working in I4.0.

- **Challenge based Learning**

”Challenge Based Learning (CBL) provides an efficient and effective framework for learning while solving real-world challenges” (The Challenge Institute 2018). CBL is an educational method with the purpose to teach students while they solve real-world challenges. The method encourages collaboration in many areas, of instance to identify, investigate and solve challenges (The Challenge Institute 2018).

- **Experimental learning (also Hands on learning)**

The meaning of Experimental learning is to learn through experience, as its name signifies (Cherry 2020). The definition of this learning method can according to the Psychologist David Kolb be explained as “the process whereby knowledge is created through the transformation of experience. Knowledge results from the combinations of grasping and transforming the experience” (Kolb 1984, referenced in Cherry 2020).

In experimental learning the student needs to reflect over experience in order to obtain new knowledge.

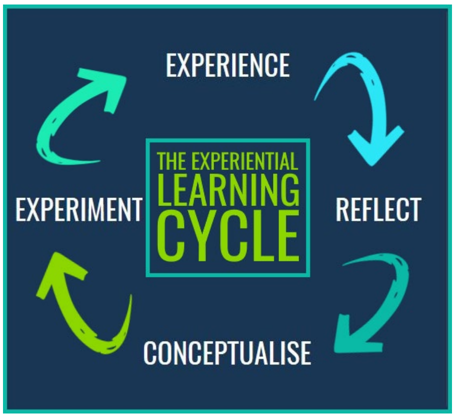

Figure 22 *The Experiental Learning Cycle* (Growth Engineering 2017)

- **Discovery learning**

Discovery Learning is an educational method of inquiry-based instruction.

Discovery Learning has five major principles. These are 1. problem solving 2. learner management 3. integrating and connecting 4. information analysis and interpretation 5. failure and feedback (Pappas 2014).

- **Just- in-time teaching**

Just-in-time teaching consists of a two-step learning process, used in order to deliver education when and where it is crucial. The first step of JITT is for the students to complete specific activities or tasks outside of education. The educator then validates these activities to identify in what areas the students need to improve. The subsequent lesson will then be adapted for these areas to guarantee that the students obtain essential knowledge. (University of Illinois Board of Trustees, et al 2020).

- **Game-based learning**

Game-based learning is an educational method utilizing games. The method can be used at different educational levels, from preschool to lifelong learning. Game-based learning is applicable in various educational purposes, such as simple memorization or more complicated learning outcomes. Either non-digital or digital games can be used when training with Game-based learning (Whitton 2012).

Whatever method is used, while the strength of the evidence varies for different methods, inductive methods are consistently found to be at least equal to, and in general more effective than, traditional deductive methods for achieving a broad range of learning outcomes (Prince and Felder 2006).

Addressing the methodologies to be used inAM LABs, it is relevant to consider a wider systemic approach, considering the completely learning environment. It is worth bringing the suggestion given in the report Curriculum guidelines for AM (PwC 2020).

Learning environment includes types of environment that are created during the educational or training programme.

The learning environment refers to both the qualities of the space (both physical and virtual) in which learning activities are situated and other intangible aspects that support and enhance the social and emotional dimensions of learning.

The learning environment can be organised in a myriad of different ways, and it needs to stem from the strategy and the specific objectives/desired learning outcomes.

Examples of objectives include stimulating multidisciplinary orientation, design thinking, creativity, team spirit, collective problem-solving, risk-taking behaviour, experimental approaches etc. It can require different forms of reality (i.e. physical, virtual, or mixed (augmented)). Multiple types of methodologies can be used and combined for achieving set objectives, such as problem-driven (or problem-based) learning, project-based learning, experience-based (or experiential) learning, collaborative learning, technology-enabled learning etc. The objectives and methodologies also define the most suitable ways of organising a physical learning environment, for example, in a form of a Learning/teaching factory, Design factory, Learning Lab, Living Lab, Innovation Hub, Makerspace etc.

4.5 How to teach industry 4.0

Every school and programme must investigate how Industry 4.0 is going to be used in the future workplace for its graduates and certify that the level of education is relevant for the students to meet the industry requirements.

According to Matthew D. Kirchner does students need to acquire knowledge and experience within the following six building blocks (Kirchner 2017).

Block 1:

Industry 4.0 is a tool usable for companies to increase their competitiveness.

In order for students to use this tool and reach the demands of Industry 4.0 they need to have a fundamental foundation of knowledge regarding the disciplines that underlie industrial success.

These disciplines include:

- An appreciation for workplace safety and safe work practices.
- An understanding of the basic throughput equation and the basic industrial need to maximize efficiency and productivity.
- An understanding of the Seven Deadly Wastes and how they manifest themselves in industry and industry-related processes.
- Familiarization with industrial Standardized Quality Systems.
- The ability to troubleshoot industrial processes and equipment.
- Soft industrial skills including collaboration, problem solving, discipline and time management.

Block 2:

Building block 2 is about the knowledge of production and manufacturing equipment essential for Industry 4.0. This equipment is for instance industrial robotics, manual and robotic welding, extruding and forming.

Block 3:

Smart Sensors and Smart Devices are the keystone of Industry 4.0. This technology collects immense volumes of information regarding its environment, embedded intelligence is used to carry out programmed functions. This is done before the information is shared amongst other systems and devices, shared via computer networks and the internet.

Paul Perkins, Chair of the State of Indiana Workforce Innovation Council and on the National Governors Association of State Workforce Board Chairs said that "the knowledge students obtain needs to expand beyond a simple understanding of smart sensor and device types" (Kirchner 2017).

Block 4:

The actual manufacturing work of machining, forming, moulding and extruding materials to products are operated by industrial equipment and technology. The process is monitored by Smart Sensors and Devices to provide feedback. These systems serve to control the whole manufacturing process in real time.

In order for students to be ready for Industry 4.0 they need to have an understanding of these subsequent system:

- Programmemable Logic Controller (PLC) Operation and Programming
- Safety PLC Operation and Programming
- Operator and Human Machine Interfaces
- Distributed I/O
- Electronic and Variable Frequency Drives
- Motor and Motion Control
- Power & Control Electronics

Block 5:

Industry 4.0 results in the fact that the industrial equipment gets more internet connected. People who can manage both Operational Technology (OT) and Information Technology (IT) have big opportunities for the future. Students need to acquire a better understanding of networks that carry data from smart devices. In order for students to get a better understanding of these networks they need to learn multiple technologies such as Network Servers, Distributed Servers, Routers, Switches, Gateway Devices. Ethernet, Foundation Fieldbus, Profibus, Wireless Communication, Linking Technologies and Multi-User Applications.

Block 6:

More data was created in the last two years than was created in the last 5,000 years of human existence. (Harris, 2016). A challenge for many companies in Industry 3.0 was the absence of data. In Industry 4.0 the challenge is rather managing the amount of available data. People that possess the knowledge to analyse data and propose measures based on the data will be necessary for the fourth industrial revolution (Kirchner 2017).

These six blocks will be implemented in the seven dimensions of education to create the ideal process for learning. The seven dimensions of learning will be presented accordingly:

Figure 23 based on *Live Lecture* (Kirchner 2017)

Live Lecture, LL, is the first of the seven dimensions for education. LL is probably the most usual method for education and refers to an educator teaching a group of people live, in person or online. A classroom lecture for instance.

Figure 24 based on *eLearning* (Kirchner 2017)

The second dimension is eLearning, also called online learning or electronic learning, and it refers to systems of formative learning through electronic resources. eLearning is in most cases accessible via the

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internet, it therefore offers learning materials accessible almost everywhere any time.

Figure 25 based on *Instructor Demonstration* (Kirchner 2017)

The third dimension is Instructor Demonstration. The term refers to the educational method where an instructor demonstrates a certain topic or task to a group of learners, in person or online. The number of learners in this method are "many", thus from two to an infinite number of learners.

Figure 26 based on *Virtual Skill Development* (Kirchner 2017)

The fourth dimension is Virtual Skill Development referring to physical training elements that will be performed virtually, through software. It is often used via computer games or visualisation like Virtual Reality. An example of an area for Virtual Skill Development could be for fitters. They can learn to assemble a product via VR before performing the work task in a real workplace. Learners can develop a foundation of experience to use in a real workplace and lower the costs since the learner does not need to train with real products.

Figure 27 based on *Instructor Interactive skills* (Kirchner 2017)

The fifth dimension is Instructor Interactive skills, IIS. IIS is performed when an instructor educates the students individually. This is often an effective way for students to learn because the specific student is in focus and is given the opportunity to advance without distraction from other students. The instructor can also adapt the education content to the needs of the specific learner, which often results in more effective learning.

Figure 28 based on *Hands-on skill development* (Kirchner 2017)

Hands-on skill development, HO, is the sixth dimension and one of the most important for learning advanced manufacturing methods. HO is practical education, with this method the student can learn through physically working with different machines or equipment.

Figure 29 based on *Portable Rotational at-Home Skills* (Kirchner 2017)

The last dimension is Portable Rotational at-Home Skills, it is excellent for distance learning. Training equipment is sent to the learners in order for them to perform specific tasks. After studies the equipment is sent back to the learning organization. New equipment and tasks are thereafter sent to the learner.

How to Teach Industry 4.0 in 2020 (LAB Midwest 2020)

4.6 Roles and responsibilities

One role regarding education in industry 4.0 is appropriate educators. These educators have certain responsibilities that are essential in order for them to create future workers who drive innovation.

The first and most vital responsibility is to have expert knowledge within the subject area, in this respect Industry 4.0. Educators do also need to go through lifelong learning in order for them to keep up to date regarding technical and educational aspects.

The educator needs to plan appropriate courses and lectures. It is relevant to use the six blocks and seven dimensions as well as various teaching methodologies, such as PBL, regarding I4.0 education.

Cooperation is one of the most important competencies regarding I4.0, it is therefore important that the educator is able to cooperate with other educators, staff and learners. The educator is also required to have good behaviour to co-workers and learners. Behaviours such as honesty, fairness, ethical conduct, a caring attitude and a correct usage of language, for instance (QEC n.d).

There are not only responsibilities for the educator but also for the learner. The first responsibilities for learners may seem obvious, but they are crucial. The learners must always strive to do their best, this should be done accordingly:

To regularly attend class on time is essential and to be prepared for the lecture with both supplies and fulfilled tasks. The learner is in this way showing respect to both the educator and the subject. The learners need to complete all assignments and pay attention in class. They must respect all educators, staff and classmates as well as taking care of the school and its equipment (Burnaby schools 2020).

There are also responsibilities for decision makers such as principals and board members.

Principals, board members and people in charge of education and curricula need to evaluate the requirements of enterprises and future workplaces for graduates and, in this way, adapt the education towards its requirements.

4.7 Definition of new EXAM 4.0 LABs

The EXAM 4.0 framework for AM 4.0 LABs must be I4.0 competency-oriented and be suitable to be implemented at VET/HVET centres.

The specific characteristics of the ultimate future AM LAB 4.0 are difficult to define. There are numerous aspects that must be taken into consideration when creating both a framework for future LABs and actually creating a new LAB. These aspects could for instance be floor space available, implementation budget, EQF-level, educational programme and the learners intended to work in the LAB. Because of these factors, it is difficult to define exactly how an ultimate LAB should be formed, the framework for future AM LABs 4.0 created within EXAM will therefore be a foundation for future LABs. The framework is based on the research carried out during EXAM 4.0 as well as the descriptions of existing LABs. This report and framework can be used as a base for creating new LABs.

Outdated software and equipment are frequently used in education, this is often a result of a low budget. Students do not get the expertise required to work with advanced manufacturing related assignments at companies if they have been in limited or no contact with Industry 4.0 related technologies. FESTO claims that schools cannot keep up with the development speed of companies, graduates will therefore not have the right expertise when applying for a job. It is therefore necessary for schools to cooperate with companies or I4.0 organisations. (FESTO n.d). The first section of the framework for future AM LABs 4.0 is regarding funding. In the tables for describing existing LABs, it is seen that all EXAM 4.0 partners have various funding methods for their institutions, thus their LABs, such as internal funds, public funds and company funds. It is good to have different funding, for instance single events or projects with different time spans.

As mentioned before, Industry 4.0 results in the fact the industrial equipment gets more internet connected. People who can manage both Operational Technology (OT) and Information Technology (IT) are big assets for the future. Students need to acquire a better understanding of networks that carry data from smart devices. It is therefore vital that a LAB includes IT-integration to a high degree, such as CAD, CAM and PLM. It is also important that the LAB includes Smart devices such as Sensors, Actuators, M2M and CPS. In order for learners to be ready to work within the advanced manufacturing sector they need to be acquainted with all relevant technologies and have expertise within several. The LAB should therefore, based on requirements for the educational programmes in the LAB, include technologies such as robotics, 3D-printers, VR/AR and CNC-machines.

The learning strategy, the educational method and the education content educated in LABs are all important aspects regarding the students' learning outcomes. Information regarding learning methods and competencies that are vital for a Industry 4.0 LAB is included in an earlier EXAM 4.0 report.

There are also many aspects of a new LAB that must be taken into consideration and validated before the LAB is created. These aspects can be:

- Number of learners intended to work in the LAB
- Life cycle of the LAB
- Targeted industries
- Main and secondary purpose of the LAB
- Technology life cycle
- Manufacturing methods

No distinct definition of what the ultimate answers to these aspects is, has been defined. It is however vital for each organisation to validate these aspects and take actions based on research in order to get the best possible outcome for the LAB in question.

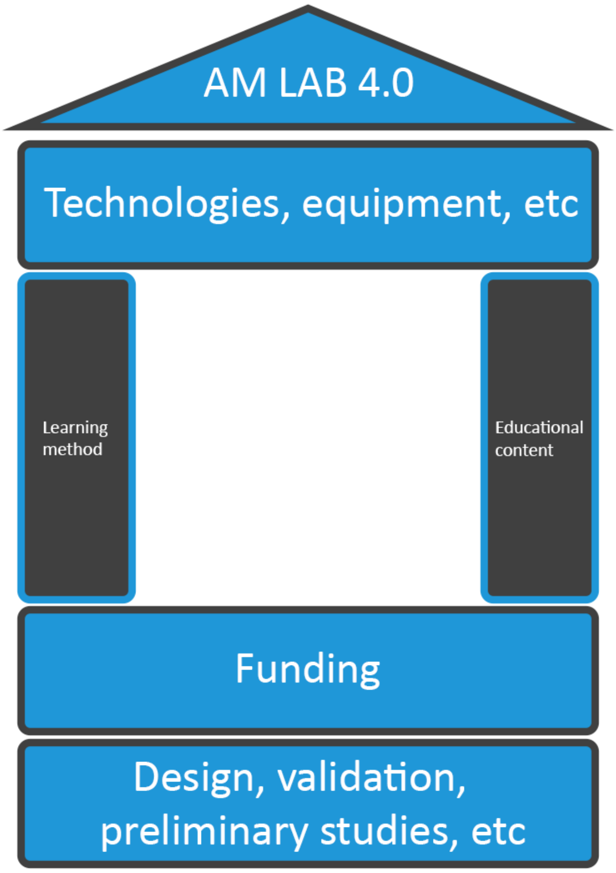

Figure 30 *AM LAB 4.0 model prototype* (EXAM 4.0)

To consider the aforementioned aspects, e.g life-cycle of the LAB, targeted industries, etc, in preliminary studies is essential in order to move on to the next step. It is an inevitable requirement to know the foundation of the LAB to be able to examine funding methods.

In the next step, funding, it is important to validate all aspects of funding. E.g funds for the creation of the LAB, funds for the maintenance of the LAB and how the LAB could be used to generate more income even though the primary usage of the LAB is for education. The EXAM 4.0 VET/HVET centre model for AM LABs can be used when designing the new LAB and validating funding. Instead of using the model as a description of an existing LAB it could be used and answered as a reference for the ultimate LAB.

The third step is the most essential when creating a new AM LAB. What educational programmes will work in the LAB and what are the EQF-levels. It is important to be aware of what educational content that will be included in the programmes and the learning methods that will be used.

The educational programmes in LAB impact the technologies and equipment that are relevant for the LAB in question. Information regarding Industry 4.0 technologies that are relevant for AM LABs are from an earlier EXAM 4.0 report.

○ 4.8 Standards, criterions, for EXAM 4.0 LAB models

Standard description for industry 4.0 LABS

A standard, a certificate, implying that some criterions are fulfilled would be beneficial for LABs. The criterions for educational LABs could ensure that the right skills and competencies are trained and learned. In this way we can have education, industry 4.0 LAB education, all around Europe training and educating the same skills and competencies even though they were not educated in the same LAB. If EXAM 4.0 LABs certificates were to be used, we could ensure that a student in Sweden learned similar skills and competencies and had the same standard education content as a student in Germany, for instance. A standard certificate for education would help companies see what skills and competencies a student has acquired wherever in Europe he or she graduated. To define new criterions relevant to Industry 4.0 would increase the standard of education all over Europe, successively increasing the European competitiveness in the national industrial sector.

An example showing how these criterions could take place:

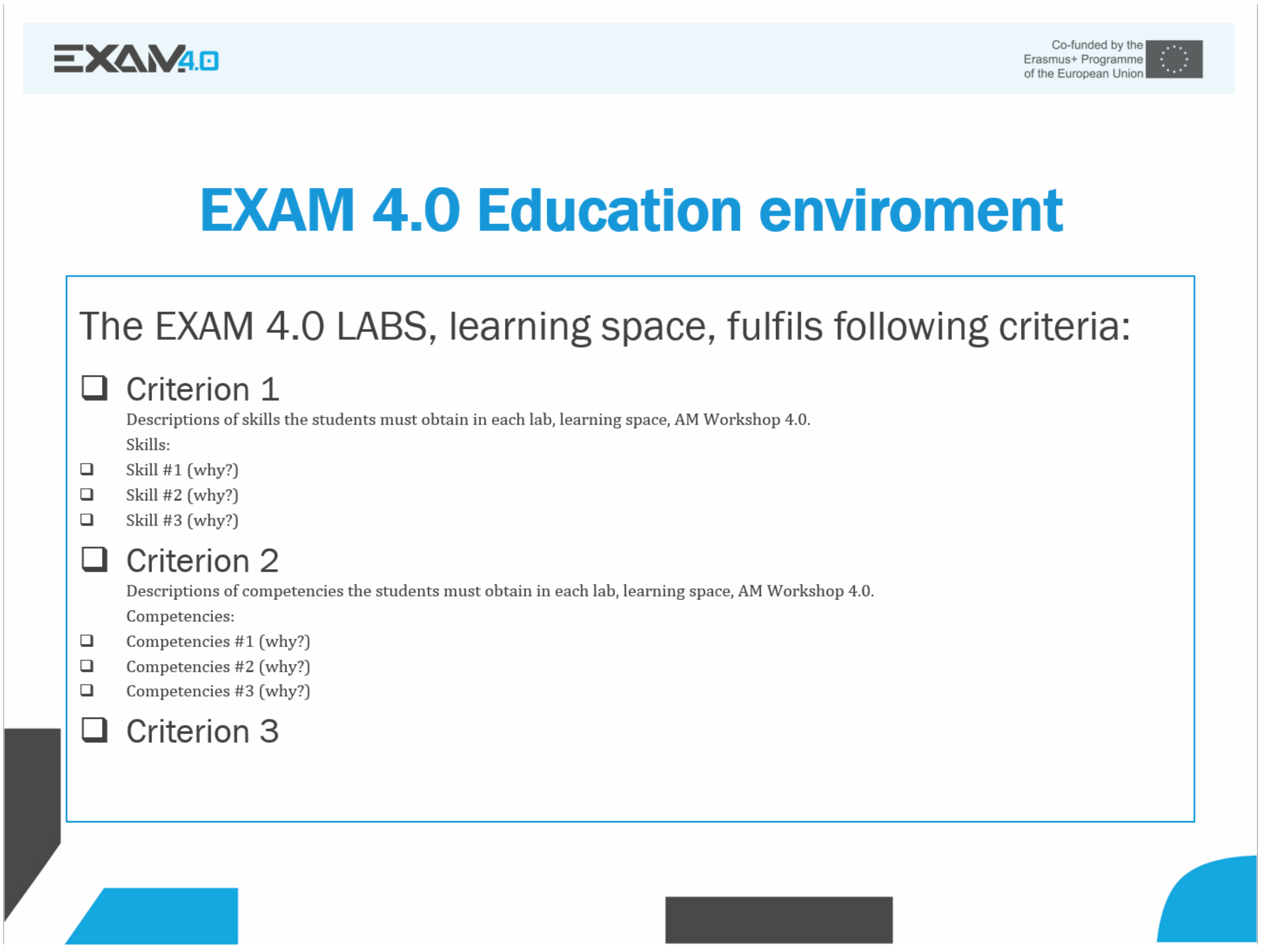

Figure 31 *Criterions for LABs* (EXAM 4.0)

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