EXAM 4.0

THE EXCELLENT ADVANCED MANUFACTURING 4.0

Methodologies for analysing and anticipating skills need in the Advanced Manufacturing sector

03

Learning dialogues

THE EXCELLENT ADVANCED MANUFACTURING 4.0

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

The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

EXAM 4.0 partners:

TKNIKA – Basque VET Applied Research Centre, CIFP Miguel Altuna, DHBW Heilbronn – Duale Hochschule Baden-Württemberg, Curt Nicolin High School, Da Vinci College, AFM – Spanish Association of Machine Tool Industries, 10XL, and EARLALL – European Association of Regional & Local Authorities for Lifelong Learning.

TABLE OF CONTENTS

DISCLAIMER: This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Acronyms and Abbreviations

AR	Augmented Reality
AM	Advanced Manufacturing
AFM	Spanish Association of Machine Tool Manufacturers
CPS	Cyper-physical-system
CPPS	Cyper-physical-platform system
DHBW	Duale Hochschule Baden Württemberg
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
IoT	Internet of Things
IIoT	Industrial Internet of Things
KET	Key enabling technologies
M2M	Machine-to-machine
OMR	Optical Mark Recognition
RFID	Radio Frequency Identification
SCM	Supply Chain Management
SME	Small-Medium-Enterprise
VET	Vocational Education and Training
VR	Virtual Reality
WP	Work Package
XaaS	Everything as a Service

Table of figures

1

Methodologies for Analysing and Anticipating Skills Need in the Advanced Manufacturing Sector

ABSTRACT

Advanced manufacturing (AM) and in a wider sense Industry 4.0 (I4.0), e.g. the implementation of cyber-physical systems along the entire value chain and a far-reaching digitalization of products and processes, is regarded as a significant agent of change in our current industrial system (see EXAM 4.0 report on Most Relevant Trends for AM). At the moment there is limited understanding regarding the skills needed to work in Industry 4.0 for the specific I4.0 technologies. Previous work on professional skills related to Industry 4.0 has been more oriented toward personality profiles for recruitment purposes rather than skills that can be developed in education. The research and discussion in this report are centred on technologies and standards and business models for and enabled by I4.0 and second, the research question aims in delivering a behavioural based competency model for Industry 4.0 building the frameworks for anticipating skills and identifying the needs in the world of work.

INTRODUCTION

A major trend in Advanced Manufacturing and Industry4.0 is the implementation of cyber-physical systems (CPS) for industrial production i.e., networks of microcomputers, sensors, and actuators embedded in materials, machines, or products that have been connected along the value chain. In addition, it also captures the digital enhancement or even re-engineering of products and services, and yields new value propositions for highly customized or differentiated products, well-synchronized product-service combinations, and value-added services. New supply chain structures with flexible processes and high equipment efficiency deliver not just cost savings but enable a range of strategic benefits such as the better handling of complex products, short time-to-market, and manufacturing on-demand. All these changes have profound implications for a company's value proposition, its competitive strategic positioning, and therefore in its Business Model.

Our research and quantitative survey (see EXAM 4.0 report on Most Relevant Trends for AM) are not without limitations. Its design is explorative and thus provides a quite high-level analysis across four countries (Germany, Netherlands, Spain, and Sweden) and case companies in the section of Industry4.0. It derives conclusions from qualitative information from focus group meetings with more than 50 companies and relies on the interviewees' insights and experience and their view on the change management perspectives. We used a convenience sampling approach, building on interviews with large European companies but also from Small Medium Enterprises, being at the beginning of their I.40 developments. To achieve validity, we aimed at ensuring a high quality of inputs by selecting interviewees with I4.0 experience, to identify future trends and validate our frameworks. After 14 interviews, we observed saturation regarding the underlying characteristics for the two EXAM 4.0 frameworks, which we expect that the general findings of the key technology processes, management approaches, and technology enablers, as well as the related competencies will build a solid base for a new qualification, curricula re-/design and work-based learning methods, improvements and lab designs.

2 Advanced Manufacturing Business Model

A business model can be defined as a management hypothesis about what customers want, how they want it, and how the enterprise can organize itself to best meet these needs, get paid for doing so, and make a profit (Christian Burmeister, Dirk Lüttgens and Frank T. Piller, 2016).

Value propositions, revenue streams, and technologies are the primary determinants of smart and connected product business models. Accordingly, traditional manufacturing companies oriented to product sales, feel increasingly compelled to revise their existing Business Models in response to new competitive dynamics and to tap into those Industry 4.0 inspired opportunities. The industry leaders of the future will build a business model that combines a set of distinctively selected Industry 4.0 capabilities and value drivers and embed them incorporate structures that are transformed accordingly. The horizontal and vertical integration of the value chain and the related interoperability expands firms' traditional boundaries due to the organization and the stakeholders' network.

I4.0 business models are expected to be designed around customer centricity, value creation networks, and, of course, the data that is generated. As a result, production plants will become smart factories and part of a future smart networked world (Kagermann et al., 2013) enabled through the Internet of things (IoT) (Wortmann & Flüchter, 2015) and the Internet of services (Buxmann P. et al., 2009). In line with these developments, the skills, flexibility, and efficiency of shop floor workers are decisive factors in ensuring accurate product specifications, meeting deadlines, and keeping the machines running. Although often neglected, human factors and especially flexibility are important elements in real production settings (Obermaier, 2019). Workers who are flexible and can perform a variety of tasks are likely to solve problems more efficiently and generate new product ideas.

THEORETICAL FOUNDATION OF AN INDUSTRY 4.0 FRAMEWORK

Based on literature and the realities of current production environments, the EXAM4.0 study identifies logical conclusions in the form of a conceptual I4.0 framework (Neaga Irina, 2019). In this context, conceptual means that it bridges existing concepts, theories, and disciplines offering new insights and broadening current thinking. Against this background, the EXAM 4.0 framework has a problem-solving focus for institutions and their curriculum design and highlights the novelty aspects of research, differing from pure reviews of extant literature.

The key elements behind the idea of Industry 4.0 can be identified as follows:

- The optimization of the value chains; that is, the horizontal integration of products and stakeholders.
- The implementation of a virtual network of autonomous, self-controlling, self-configuring, knowledge-based, sensor-equipped, manufacturing resources.
- The interchange of data in and between the different phases of a product life cycle.

This can be summarized as the four components of Industry 4.0: **instrumented**, **interconnected, inclusive, and intelligent.** Together with the three stages of the manufacturing process - **designing, making, and using –** they build the basis of the I4.0 framework.

The ingredients for Industry 4.0			
Instrumented	**Interconnected**	**Inclusive**	**Intelligent**
Data Devices contain sensors, actuators and software that generate data	**Connectivity** An information network connects devices together; gathers and processes the data either at the edge of the network or centrally – selectively	**Context** Industry knowledge, data external to the network (weather etc.) adds context to the data	**Decision Making** Machine learning, predictive analytics and cognitive computing makes sense of the data; decentralized decision making, move towards autonomy

What Industry 4.0 enables		
Design	**Make**	**Use**
Integrate - use of existing products by equipping them with sensors to bring them into the connected environment **Predict** - design new products based on utilisation of existing products and market reaction to concepts **Innovate** - insight from sensor data can guide equipment usage and new product or service design based on customer use and use across a network	**Optimise** - predictive maintenance of production lines optimises uptime and maximises throughput **Fulfil** - meet market demands by providing what is most utilised **Extend** - machines will come with intelligence pre-built. The applications for those product-service hybrids will become revenue streams **Employ** - new roles for product and experience designers, application developers, data scientists equipment/network production, implementation and support.	**Satisfy** – predictive maintenance of products assures optimal usability and availability, optimised supply chains assure availability **Safety** – hazardous tasks and environments are delivered by robots. **Sensory** – new ways for humans to interact digitally with machines through voice, sight, touch and movement.

Figure 1: Key elements of Industry 4.0 (IBM 2019)

In the study “Curriculum Guidelines 4.0 – Future-proof education and training for manufacturing in Europe'', published by the executive agency for small and medium-sized enterprises (EASME) and Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs of the (PricewaterhouseCoopers EU Services EESV, 2020), the research group investigates the challenges education and training providers are facing by developing new approaches and curricula to provide employees with needed skills for Industry 4.0 (PricewaterhouseCoopers EU Services EESV, 2020). Industry 4.0 focuses on the end-to-end digitisation of all physical assets and integration into digital ecosystems with value chain partners. The following framework developed by the research group distinguishes four key technological developments in Industry 4.0:

(1) digitisation and integration of vertical and horizontal value chains

(2) digitisation of product and service offerings

(3) digitisation of business processes and way of working, and

(4) digitisation of business models and customer access.

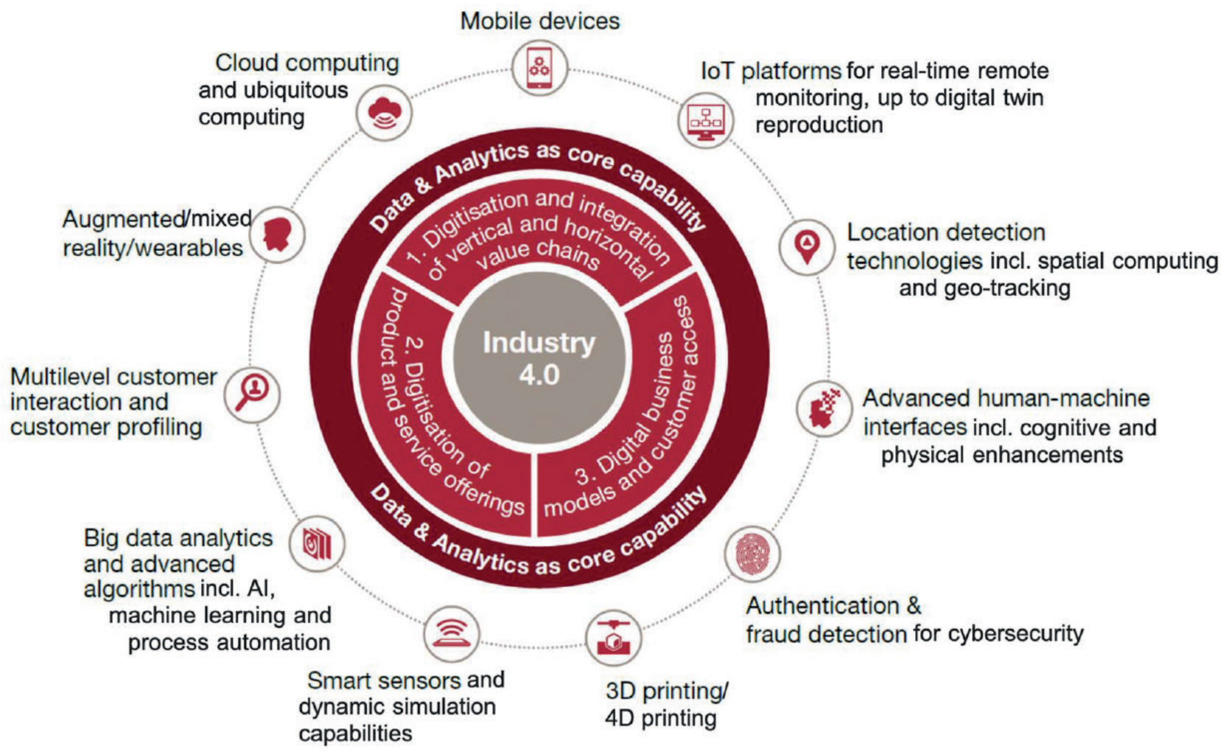

Figure 2: Industry 4.0 framework (PricewaterhouseCoopers EU Services EESV, 2020)

In current Advanced Manufacturing environments, increasing knowledge building, decision-making skills, and social interaction among team members on the shop floor is a major topic. The transformational ability of digital technologies to **knowledge-intensive production** environments is expected to be one of the advancements in human-centric manufacturing for companies to improve efficiency and productivity in order to survive in competitive markets. (Hannola et al., 2018). These challenges can be linked to four facets of the individual knowledge processes of workers – **knowledge acquisition, knowledge discovery, knowledge transfer, and knowledge sharing.** These practices can help manufacturing companies achieve necessary capabilities, such as problem-solving, dynamic learning, strategic planning, and decision-making (Zack et al., 2009).

The increasing complexity of products and the importance of product- and production-related knowledge have led to the introduction of knowledge work tools at all levels of manufacturing organisations (Hannola et al., 2018). Production workers are becoming knowledge workers, and expectations are becoming more demanding regarding their skills. The underlying idea of smart factories highlights the importance of information and knowledge processes and the efficient and effective utilisation of knowledge on all levels of operations, including production workers on the shop floor. This will have significant effects on the job content of production workers, such as introducing information and knowledge processing, decision-making, and problem-solving. Advanced manufacturing organisations have the opportunity to develop solutions that support worker-centric knowledge management in their production environments, utilising the available versatile technological possibilities (Hannola et al., 2018).

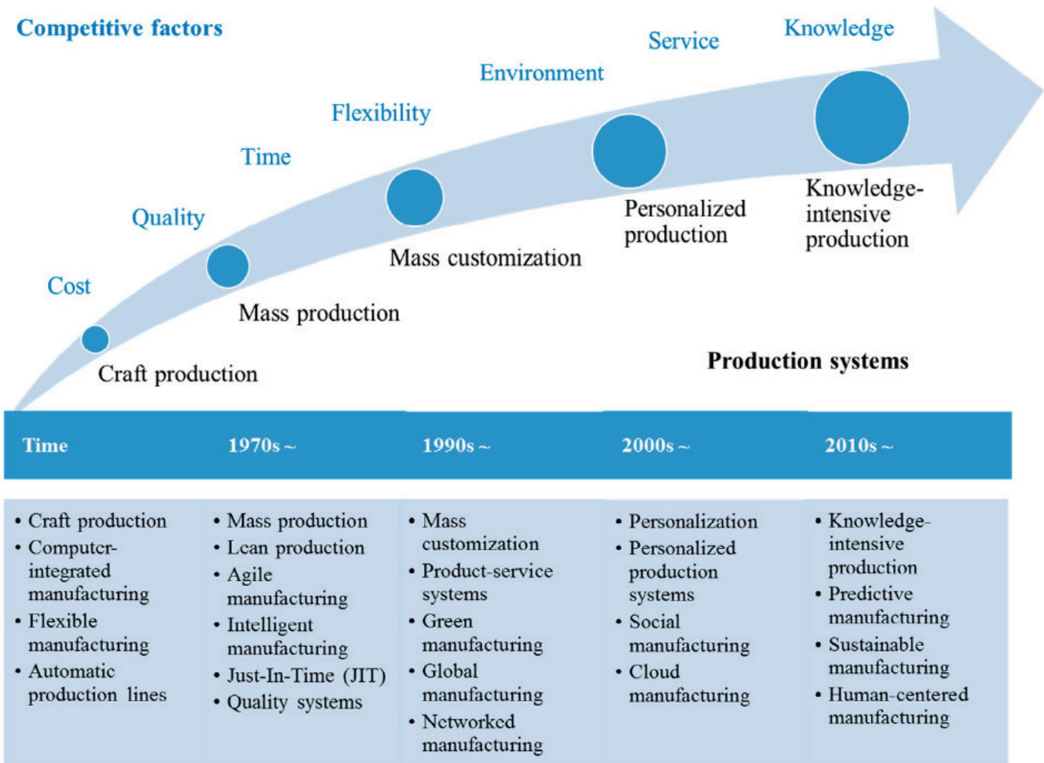

Figure 3: The development of production models and manufacturing systems (adapted from (Tao et al., 2017); (Hannola et al., 2018)

Therefore, information and knowledge management processes are key elements of the I4.0 framework.

3 Determination of the EXAM 4.0 Framework

According to the discussion in the previous sections the EXAM 4.0 framework for Industry 4.0 should take into account the following facts:

- there is no ‘technological determinism’,
- there is a need to address different skills needs according to the specific Industry 4.0 ‘biotopes’,
- there are different workforce segments and types of organisational structures,
- different sectors are using different subsets of the technologies,
- there are different product life cycles according to which different development and operation processes need to be supported.

As such a framework for assessing the training needs or the work-readiness of the learners should take into account all the above aspects and therefore it should be multidimensional. We are proposing to employ four different dimensions to define the educational needs namely:

- I4.0 Ecosystem: Governance and Strategy, Leadership, People Integration and Change
- I4.0 Functions, Core Processes (cross-functional key management processes)
- I4.0 Technology Enablers
- I4.0 Applications (Smart Solutions, Smart Innovation, Smart Supply Chain, Smart factory)

In Figure 4 we present the EXAM 4.0 framework where it is indicated that by combining these four different facets, we can produce balance training proposals for different study programmes and institutions. These four dimensions have to be analyzed for producing the training proposals for each different study programme.

INDUSTRY 4.0 ECOSYSTEM

Governance and Strategy

First, a basic understanding of the trends and impact is needed for all learners and study programmes. Reflection is also needed on how to strengthen manufacturers' competitiveness in a more complex environment of players from within and outside the classical manufacturing value chain. Leveraging the fusion of the physical and the virtual world into cyber-physical-systems strongly requires a collectivity of technologies such as machine-to-machine communication, cloud computing, and advanced analytics.

Leadership

Second learners need to understand the Industry 4.0 transformation, what it will require in terms of leadership, and thorough governance of the transformation process to secure a consistent implementation instead of disconnected initiatives in organizational silos.

People Integration & Change

Third, learners need to be educated about the changes of the human factor and how the digital future will confront employees with radically new working modes and demand new capabilities. Finally, manufacturing operating models must explain how they overcome today's rigidity and respond to the business agility of the new industrial era.

INDUSTRY 4.0 FUNCTIONS AND CORE PROCESSES

Digitized manufacturing processes will also bring about big challenges for many manufacturers in terms of employee skills. Institutions need to understand the new manufacturing processes and new capabilities need to be trained and will be needed in many functions, not only in IT-related domains. However, IT and Software will become an integral part of manufactured products, so educators have to teach the corresponding skills. As an example, today's machine operators will have to become analysts of production-related data, able to derive meaningful insights into process quality from a bulk of information.

An "I4.0 functional area" summarizes the applications in the company related to Advanced Manufacturing management processes (Zhong et al., 2017). They can be understood as cross-functions or I4.0 core processes within corporate divisions and are valid such as production, logistics, and maintenance functions.

The five "I4.0 functional area" are:

- Data acquisition and processing,
- Assistance systems,
- Networking and integration,
- Decentralization and Service orientation,
- Self-organization and autonomy

Data Acquisition and Processing

- Sensor technology / RFID / barcode
- Data analysis / big data analysis
- Documentation and data management
- Simulation (product, production, plants, etc.)
- Data security

Assistance Systems

- Visualization, augmented reality
- Mobile devices
- Human-machine interaction
- 3D printing/scan
- Simulation (product, production, etc.)

Networking and Integration

- Vertical and horizontal integration
- Flexible networking of systems, processes, and products
- Internet of Things
- Cloud computing

Decentralization and Service Orientation

- Apps, web service, XaaS
- New business models
- Service orchestration
- Decentralized control
- Versatility

Self-organization and Autonomy

- Control loops / self-organization
- Self-configuration / optimization
- Cyber-physical systems
- Process monitoring

(more information can be found in the report on Most Relevant Trends for AM)

TECHNOLOGY ENABLERS

According to various studies and reports, there are ten technological areas that are driving developments in Industry 4.0 initiatives.

These key technologies are:

- Embedded systems (CPS)
- Cloud computing
- Big data and analytics
- Communication and networking
- Additive manufacturing
- Robotics
- Augmented reality
- Cybersecurity
- Machine-to-machine communication
- Actuators and sensors

Each industry sector has different technologies in use since different production processes are employed. The list may be adapted according to specific needs.

Smart Applications

In many industry sectors, the following four main applications and eight value drivers are key elements of the new industrial paradigm. ***Smart Solutions, Smart Innovation, Smart Supply Chains, and the Smart Factory*** are the fields in which manufacturers are realizing enormous potentials by digitizing their business. While Smart Solutions and Innovation primarily leverage company growth, Smart Supply Chains and Factories mainly drive efficiency.

Smart Solutions

Smart Products are cyber-physical systems (CPS) providing new features and functions based on connectivity. Smart products integrated into modern production flows can self-process, store data, communicate and interact within the industrial ecosystem. Today smart products don't only provide their identity, but also describe their status and lifecycle history. They are capable of computing algorithms and machine learning, which makes them adept at processing further steps, including the production stages resulting in the finished product and also upcoming maintenance operations.

Smart Services open up paths for entirely new business models and markets through innovative service offerings and delivery models.

In smart manufacturing, solutions learn and interpret patterns and related outcomes, which will improve fault predictions, security and productivity over time.

Smart Innovations

The digitalisation of industry will not only transform value-creation processes but also give rise to new business models and 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 have to 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. In an interconnected Industry 4.0, new impulses come from a multitude of sources outside the own organization, and they have to be proactively integrated into an open innovation process.

Smart Supply Chain

Smart Supply Chains are highly integrated and automated, enabled by the use of digital technologies and cyber-physical systems. A networked production environment and interconnected engineering platforms form the basis for these networks. Furthermore, interfaces between companies in terms of organizational structures, processes, and IT as well as standardized, portable data formats are the key enablers for flexible collaborations in manufacturing. In contrast to *Agile Collaboration Networks*, which build on the horizontal integration of supply chains, vertical integration based on digital technologies allows companies to drive value through transparency and process automation. In such *Connected Supply Chains*, operating costs can be dramatically reduced.

IoT takes supply chain communications to another level: the possibility of human-to-things communication and autonomous coordination among ‘things’ while being stored in a facility or being transported between different supply chain entities. These new capabilities offer tremendous opportunities to deal more effectively with SCM challenges. IoT provides new levels of supply chain visibility, agility, and adaptability to cope with various SCM challenges (Ellis S. et al., 2015).

Smart Factory

The ***Smart Factory*** constitutes the fourth pillar of Industry 4.0. CPPS will be its basis. Through the networked array of machines, a new level of self-organization and process optimization is enabled in the form of ***Decentralized Production Control***. Secondly, the exploding wealth of production-related information also provides the basis for ***Data-driven Operational Excellence***.

In the age of Industry 4.0, factories consist of several smart units: machines coordinate manufacturing processes without any human interaction, service robots and people work side by side in the assembly shop, driverless transport vehicles run logistics tasks on their own.

The literature has proposed many definitions of the term “smart factory”. We select a comprehensive definition by Radziwon, who defined the smart factory as “*a manufacturing solution that provides such flexible and adaptive production processes that will solve problems arising on a production facility with dynamic and rapidly changing boundary conditions in a world of increasing complexity. This special solution could, on one hand, be related to automation, understood as a combination of software, hardware, and/or mechanics, which should lead to optimization of manufacturing resulting in a reduction of unnecessary labour and waste of resources. On the other hand, it could be seen in a perspective of collaboration between different industrial and nonindustrial partners, where the smartness comes from forming a dynamic organization” (Radziwon et al., 2014)*. (more detailed description see EXAM 4.0 report on Most Relevant Trends for AM).

Smart factories are enabled by cyber-physical systems and the Internet of Things. Cyber-physical systems (CPS) create a virtual copy of the factory (a digital twin) through sensors, actuators, and microcontrollers (Lee et al., 2017).

They have x components:

Connection (sensor and networks)

Cloud (data on demand)

Cyber (model and memory)

Content (meaning and correlation)

Community (sharing and collaboration)

Customization (personalization and value), where information is strategically used to give value to the system

Cyber-physical systems have five levels of development:

Connection level (communicable)

Conversion level (informational)

Cyber level (controllable, automated)

Cognition level (early awareness, predictive maintenance)

Configuration level (self-configure, intelligent)

The value drivers introduced above do not represent IT requirements, but the business opportunities and needs created by a digitized industrial sector. However, it is the shift to digital technologies that so fundamentally affects the manufacturing sector and enables these value drivers. The concept of Industry 4.0 arises at a time as digital technologies coalesce into an ecosystem of ‘Digital’. The successful transformation towards Industry 4.0 depends on the mastery of this ecosystem.

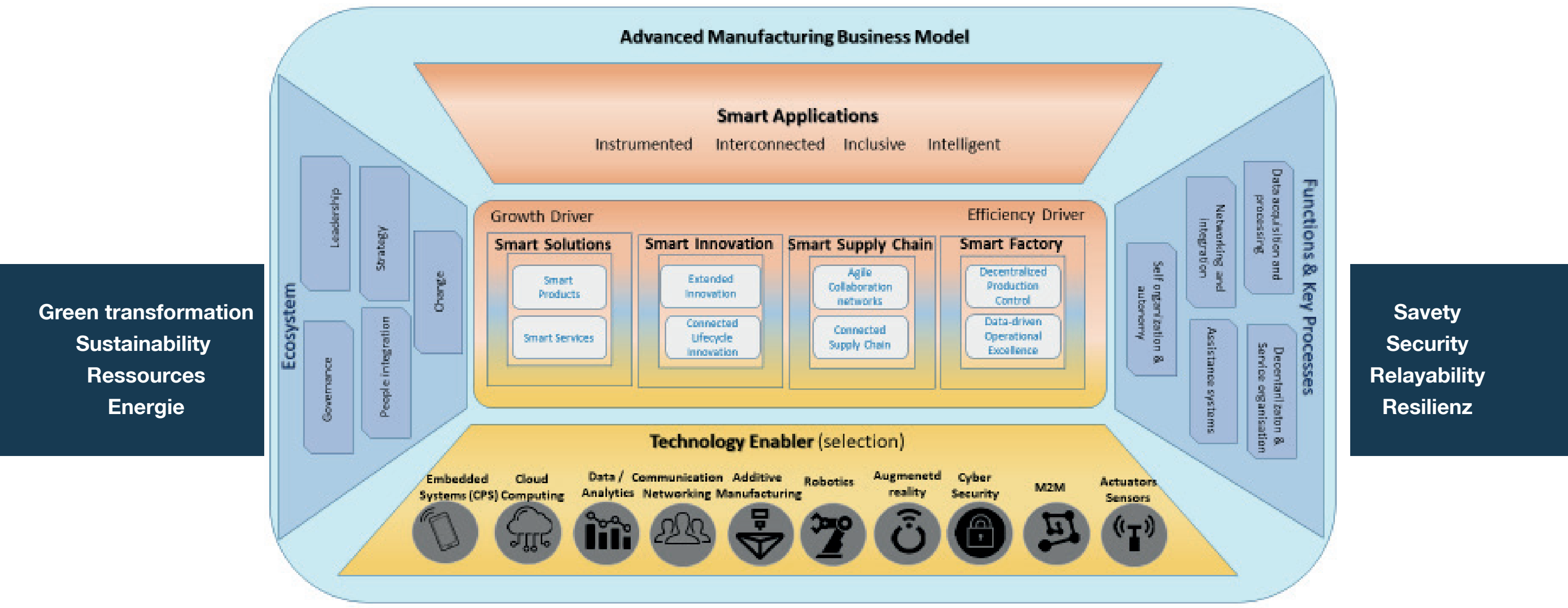

Figure 4: Exam4.0 framework (adapted from Capgemini Consulting 2019)

DEFINITIONS

The term competency was first introduced by McClelland (David C. Mc Clelland, 1973), as he described this as the ability to deliver a superior performance. The behavioural approach focuses on attributes that go beyond the cognitive ability as self-awareness, self-regulation, and social skills. This approach argues that competencies are fundamentally behavioural unlike personality or intelligence and can be taught through learning and development (David C. Mc Clelland, 1973). As Spencer and Spencer (1993) defined it, a competency includes: “motives, traits, self-concepts, attitudes or values, content knowledge, or cognitive or behavioural skills – any individual characteristic that can be measured or counted reliably and that can be shown to differentiate significantly between superior and average performers, or between effective and ineffective performers.” (Chouhan V.S. & Srivastava S., 2014).

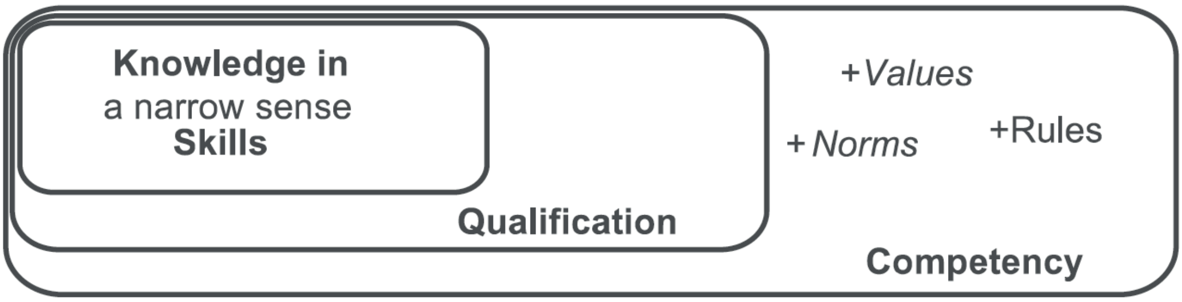

Figure 5: Source Relation of competency, qualification, skills, and knowledge (Heyse & Erpenbeck, 2009)

The following examples are showing various directions and definitions used with regard to competencies that show how this concept has been used and evolved, from the description as a simple characteristic to a set of behaviours.

Competency vs Qualification: Competence, concerning occupational standards-based qualifications, has been defined as ‘the ability to apply knowledge, understanding, and skills in performing to the standards required in employment. This includes solving problems and meeting changing demands’ (Beaumont, 1996).

The following definition about qualification could be found in the literature “Qualifications … describes the ability … meaning knowledge, qualifications, capabilities that persons possess and that are used in practicing a professional activity” (Teichler U. & Schomburg H., 2013).

So the term qualification is a specialized term used more in the case of education and training. The qualification defines the requirement for education and it should be accompanied by issuing a certificate.

Competency vs Skill: Many competency studies are discipline-related and try in defining the competency or specific skills for a particular job (Willis, 1990). Marcolin, Compeau, Munro, and Huff (2000) define a competency "as the user's potential to apply technology to its fullest possible extent so as to maximize the user's performance on specific job tasks" (Chouhan V.S. & Srivastava S., 2014). This is a clear skill-based view of the competency concept. The skill-based approach assigns a predefined task and defines the skills that a person should bring to fulfill this task.

There is however a difference between skill and competency. A skill is predefined and job-specific. The assessment of knowledge and skills is quite different from the assessment of competencies:

- **Knowledge and skills are job or occupation-specific**, and the domain of knowledge and skills across the whole world of work is potentially limitless.

- **Competencies are generic** in that they apply across all occupations and jobs.

Competencies determine whether or not people will acquire new job knowledge and skills, and how they will use that knowledge and skills to enhance their performance in the workplace.

The measurement of competence at work involves the assessment of performance in the workplace against some predefined set of occupational or work-related knowledge and skill standards. These standards define the performance criteria associated with competence in the workplace. There is a limited number of available competencies since the competencies define the ability to learn the needed skills for a job (Bartram, 2012).

Competency vs Knowledge: The concept of knowledge is also closely related to competency and often interchangeably used. In this concept, a combination of explicit and tacit knowledge completes an individual and gives him the ability to perform well (Basellier et al., 2001).

Similar to the concept of skills however there is a difference between competency and knowledge. While knowledge describes the know-how about a specific topic or a specific job, and the variations of knowledge that can be adapted is limitless in the world, a competency describes the ability to adapt this knowledge while required on the job and apply it accordingly for achieving the needed results (Bartram, 2012). There is however a strong correlation between the two topics and knowledge is a part of the competency concept.

For conceptualizing the topic (Figure 6) "Competencies for Industry 4.0" is separated into two parts. It consists of the parts "Competencies" and "Industry 4.0". In this context Industry 4.0 is often referred also to as Advanced Manufacturing.

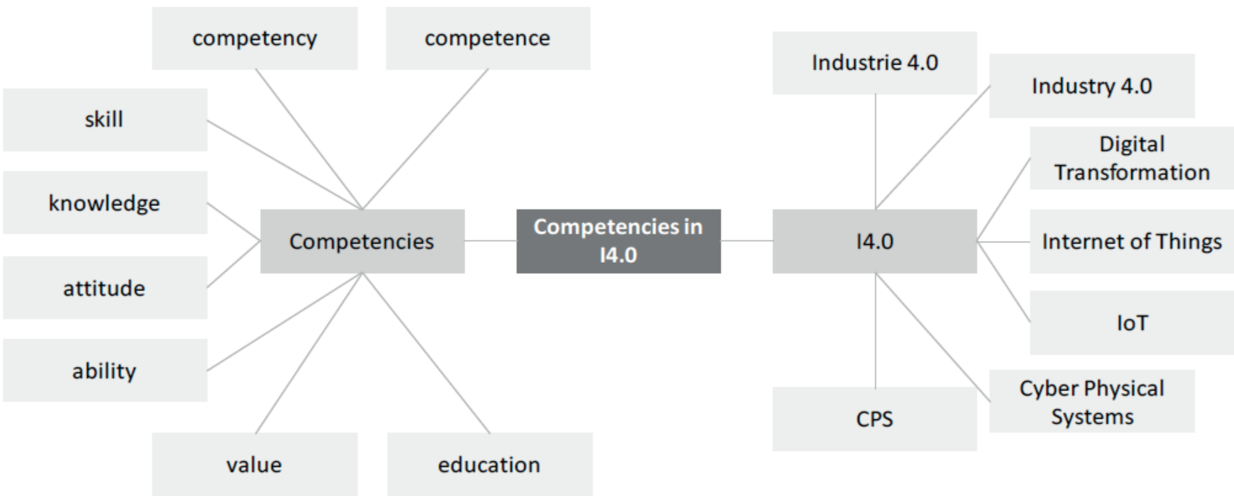

Figure 6: Conceptualization of the Topic (Source: Professional Qualification in "Industrie 4.0": Building a Competency Model and Competency-Based Curriculum – 2019 Loina Prifti

For the EXAM 4.0 study, we use the definition of Bartram, who defines competencies as: “sets of behaviours that are instrumental in the delivery of desired results or outcomes”. The EXAM 4.0 framework will give an overview of the competencies that should be taught to individuals for successfully working in I4.0.

COMPETENCY TYPOLOGIES

Researchers have tried to give a broader and more holistic view of the concept of competencies. Therefore, a typology of competencies can be recognized in the literature. This typology comprises usually four categories (Figure 7) that slightly vary from one another, however, the basic concept is the same. Solga, Ryschka, and Mattenklott (2011), Kauffeld (2006) and Sonntag (2004), propose four typologies as described below:

Functional Competencies: Functional or professional competencies describe specific abilities and professional skills, which are required to solve clear-defined tasks. The functional approach was developed in the UK in the 80s.

Methodological (Meta) Competencies: This typology describes flexible usable general planning- and decision-abilities, which qualify an individual to independently solve new and complex problems (Solga et al., 2011). Delamare Le Deist and Winterton (2005) define this as cognitive competency and relates it to the term of knowledge.

Social Competencies: Egeling and Nippa (2009) call it social or interpersonal competency, Delamare Le Deist and Winterton (2005) define it also as social competency by including behavioural and attitudinal competencies in this typology. Social competency comprises communicative and cooperative abilities and skills, which qualify to realize individual or shared goals in an accepted way during social interaction, which are defined as social competencies (Solga et al., 2011).

Self- or Cognitive Competencies: This area covers professional relevant attitudes, values, and personal characteristics, which influence the professional self-reflection and the motivational and emotional direction of professional activities (Solga et al., 2011). Openness to new experiences, self-efficacy, optimism, and proactiveness are some of the included competencies.

The holistic or multi-dimensional approach describes competencies as a **collection of individual competencies** required from an individual – and **organizational competencies** required on the organization level to achieve the desired results (Straka, 2004). This approach was followed in France, Germany, and Austria (Delamare Le Deist & Winterton, 2005). Most of the other European countries follow either the UK or the French or German approaches (Delamare Le Deist & Winterton, 2005).

In Germany, the first movement towards competencies was in the 80' with the introduction of key qualifications (Schlüsselqualifikationen) that included personal competencies as 'ability to act autonomously and to solve problems independently, 'flexibility', 'ability to cooperate, 'practical ethics and moral maturity' (Delamare Le Deist & Winterton, 2005). However as already mentioned, qualification focuses more on the ability to conduct a job, while competency is a broader concept including also general abilities and the capability to act in certain situations (Arnold, Nolda, & Nuissl, 2001).

An orientation towards competence and the associated notion of outcomes has to do with the specificity of the notion of 'Kompetenz' that has come to be accepted in the German-speaking countries, which is (still) in some respects contrary to the connotations of the English term competences. The main difference is that the English term 'competences' describes not the learning process but its outcome, whereas the German word is input-oriented. From the standpoint of the German-speaking countries, therefore, although the competence development models of the English-speaking world offer indications as to the development of competences and hence also of curricula, they do not determine these, and this ultimately gives rise, to the world of training, to the forgoing of regulation of the process of learning and training proper and hence of the structure and organisation of training and specifically in the dual education systems of HVET (Bohlinger 2008).

Competences	***Kompetenz***
Object-related	Subject-related
Self-contained learning units for the purpose of certification	Category for broadly based potential freedom of disposition
Qualification-related	Content-related
Training standards based on vocational tasks and situations	Training standards based on specialised vocational knowledge, reflection and experience
Pathways to acquiring competences tend not to be formalised	Pathways to acquiring competences tend to be highly standardised and formalised
Basic idea: confirmation and certification of personal abilities and skills → orientation towards output	Basic idea: standardisation of a learning process with a view to broadening knowledge and freedom of disposition → orientation towards input

Table 2: Differences between 'Kompetenz' and competences (based on Clement, 2003)

The concept of competency was further adapted in 1996 in Germany by defining learning fields or competencies for every curricula (Delamare Le Deist & Winterton, 2005; Straka, 2004). Nowadays it is usual to define competencies in every curricula or training. A standard typology divides these competencies in *"elaborating vocational action competency (Handlungskompetenz) in terms of domain or subject competency (Fachkompetenz), personal competency (Personalkompetenz) and social competency (Sozialkompetenz)" (Delamare Le Deist & Winterton, 2005). Furthermore the concept of domain competency is used that can be defined as "Domain competency describes the willingness and ability, on the basis of subject-specific knowledge and skills, to carry out tasks and solve problems and to judge the results in a way that is goal-oriented, appropriate, methodological and independent."* (Delamare Le Deist & Winterton, 2005). The concept of competency in Germany has earned a high relevance.

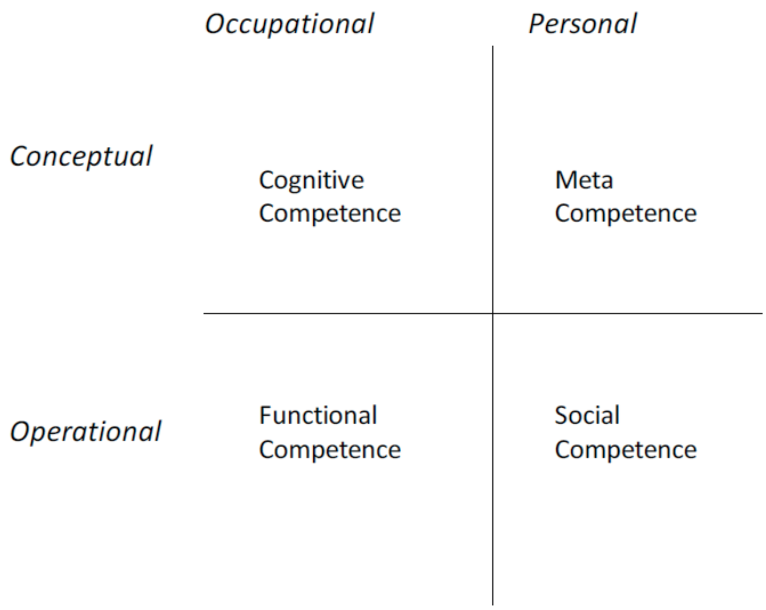

Figure 7: Typologies of Competency (Source: Prifti – 2019 based on Delamare Le Deist and Winterton – 2005)

The study "Skills for Key Enabling Technologies in Europe", also referred to as "KETs Initiative Study", prepared by PwC Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs of the European Commission presents the skill requirements for "manufacturing professionals 4.0", Skills. (PricewaterhouseCoopers EU Services EESV, 2020)

KETs have been defined by the European Commission as knowledge-intensive technologies associated with high R&D intensity, rapid innovation cycles, high capital expenditure, and highly skilled employment. KETs enable process, goods, and service innovation throughout the economy and are of systemic relevance. KETs currently include the following six areas of technology: micro-/nano electronics, nanotechnology, photonics, advanced materials, industrial biotechnology, and advanced manufacturing technologies.

KETs Skills Initiative focuses on the current and anticipated needs of employers concerning KETs skills and the ways to best satisfy those needs.

Nowadays, given continuous changes in business, cultural, legal, and market environments, non-technical skills become as important as technical skills. Working in multidisciplinary international teams to serve customers from various locations across the globe requires skills related to communication, entrepreneurship, negotiation, problem-solving, etc.

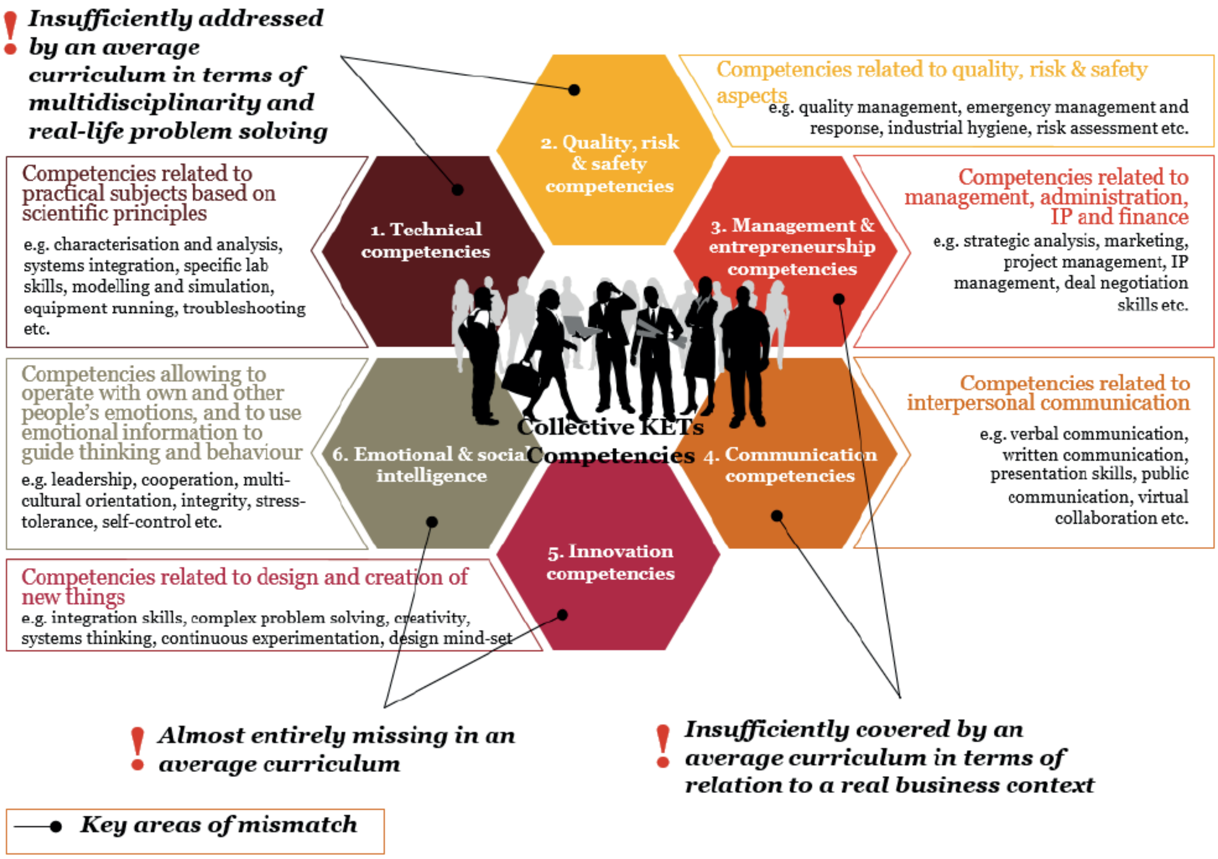

Figure 8: Collective KETs competencies and key areas of mismatch
Source: http://skills4industry.eu/sites/default/files/2020-03/Curriculum-Guidelines-Brochure.pdf

Required skills for employees in Advanced Manufacturing

To identify required skills and qualifications for employees in Industry 4.0, the KET study considers three distinctive and interrelated tiers, referring to the approach of the VDI White Paper of 2015. Starting with Tier 3 which covers factors that influence the future workforce. As a result, the influences portrayed in Tier 3 evoke changes in employee's tasks, presented in Tier 2. The developments concerning the future workforce and adjusted tasks jointly form the base to identify the required skills and qualifications of employees for Industry 4.0 (Tier 1) (PricewaterhouseCoopers EU Services EESV, 2020).

Tier 3 describes influential factors which have an impact on the workforce such as tools, technologies, organization, structure, working environment, intra-, and inter-organizational cooperation. Tools and technology as influential factors are expected to evoke a decreasing need for manual and routine tasks, active use of collaborative robotics as well as optimized human-machine interfaces that allow employees to decide competently. Furthermore, the tools and technologies of Industry 4.0 ensure workers of the AM real-time information perform efficiently. In return, employees need to be able to control and monitor production processes based on analysis data. In Industry 4.0, job rotation and job enrichment are anticipated to facilitate as well as increased responsibility and decision-making power, due to organizational changes and transition towards a flat organizational structure. In addition, the working environment is expected to improve for workers of the AM, including active use of devices, assistance systems, and automation of challenging or dangerous tasks. Furthermore, the study forecasts the increasing importance of teamwork, communication, particularly between cyber-physical-systems, and cooperation with external partners such as research institutes (PricewaterhouseCoopers EU Services EESV, 2020). As a result, the developments described in Tier 3 will induce changes in the associated tasks of employees of Industry 4.0, presented in Tier 2. Monotonous and challenging tasks are anticipated to decrease in Industry 4.0. However, the changes are anticipated to enable workers to execute a greater variety of job assignments and a transition towards tasks that will be predominantly performed through devices and assistance systems (PricewaterhouseCoopers EU Services EESV, 2020). The developments and changes described in Tier 3 and Tier 2 jointly form the base of Tier 1, including skills and qualifications that are required in Industry 4.0. Key qualifications for employees in AM are forecasted to include both technical and non-technical skills. The study emphasizes increasing importance concerning data management skills, cybersecurity, decision-making-methodologies as well as computer programming, coding skills, and interdisciplinary understanding of processes, organization, and technologies. Non-technical competencies demanded in Industry 4.0 imply adaptability, flexibility, communication skills, teamwork skills, and self-management skills.

Moreover, employees of Industry 4.0 are expected to be willing to continuously improve and have a mindset towards lifelong learning. The results presented above can be proven by a recent study from Deloitte and The Manufacturing Institute (2018). In their study "2018 Deloitte and The Manufacturing Institute skills gap and future of work-study" the authors present similar results regarding future skill needs, supporting their conclusions by key outcomes of an online survey (PricewaterhouseCoopers EU Services EESV, 2020). The results imply skills such as technology and computing skills, digital skills, programming skills for robots and automation, ability to work with tools and technology, and critical thinking skills. Regarding technical skills required of employees in the AM, key outcomes of the survey emphasize the ability to interact with human-machine interfaces, data management skills, and specialized knowledge of technologies and processes. Non-technical skills described in the key outcomes of the survey also present similarities between the studies. According to the skills gap survey, skills concerning adaptability, flexibility, creativity, critical thinking as well as a general mindset towards lifelong learning are anticipated to increase.

Categories of Competences for Key-enabling Technologies

The PwC EU Service identified six categories of competences for Key enabling technologies for high-tech professionals (KET) including the results of required skills in the AM institutes (PricewaterhouseCoopers EU Services EESV, 2020). The categories of competencies for KETs include competences regarding

- Technical subjects
- Quality, risk, and safety
- Management & Entrepreneurship
- Communication
- Innovation
- Emotional intelligence

Technical competencies are related to practical subjects based on scientific principles, for example, coding, computational thinking, mathematical modeling, and simulation. Due to the knowledge-intensive nature of Key Enabling Technologies, the latter competencies are described as the heaviest category regarding required knowledge and skills (PricewaterhouseCoopers EU Services EESV, 2020).

The second category concerning quality, risk, and safety implies competencies such as quality management, quality control analysis, emergency management, and response, industrial hygiene, and risk assessment. Employees working with KETs need to operate with a high level of accuracy because of highly expensive equipment. Therefore, employees working with KETs need to be able to concentrate over a long period and to keep attention to detail. They are also expected to follow stringent and specific quality and safety procedures (PricewaterhouseCoopers EU Services EESV, 2020).

Management and entrepreneurship present another category of competences for KETs, including market analysis, strategic developments for product demonstrations with significant risk, marketing, project management, and R&D management. Competencies of this category refer to the ability to acquire and manage large investments and to coordinate international teams (PwC EU Services 2020: 37).

Competencies referring to the category of communication relate to the interpersonal exchange of information, verbal as well as written communication, and virtual collaboration. In the study, PwC EU Service emphasizes the importance of diverse teams in KETs, therefore, competences related to communication are key competences required of employees working in an advanced manufacturing environment. Employees need to be able to work productively, drive engagement, integrate and establish as a member of virtual teams (PwC EU Services 2020: 37).

The fifth category of competences regarding innovation refers to the designing and creation of new things. This category implies competences such as integration skills, complex problem solving, creativity, and systems thinking. The competences of this category pertain to the ability to use and combine different disciplines into joint solutions to solve complex problems in an advanced manufacturing environment (PwC EU Services 2020: 37).

The last category of KETs competences, emotional intelligence, includes the ability to operate with own and other peoples' emotions and to use these to guide thinking and behaviours. Competences implied in the aforementioned category are leadership, cooperation, a multi-cultural orientation, stress tolerance, and self-control (PwC EU Services 2020: 37).

Moreover, the competences presented in the framework are distinguished between general and specific competences or rather KET-specific and multi-KETs competences. General or multi-KETs competences present a common core of competences and apply to the majority of high-tech employees regardless of their respective field or job profile. Specific competences, on the other hand, are unique to particular domains or job profiles. These competences imply for example highly specialised technical knowledge, skills required when working with specific equipment, and in-depth knowledge of non-technical subjects and topics that do not refer to all high-tech professionals. Furthermore, PwC EU Service adds that the differentiation between general or specific competences also depends on the occupational level (PwC EU Services 2020: 20).

By identifying categories of competencies for KETs, PwC clustered and structured required competencies and skills for working in an advanced manufacturing environment.

INDUSTRY 4.0 SKILLS AND COMPETENCES

The skills evolution of qualified personnel and junior employees for current and future changes in the workplace will require employees who are 4.0 specialists and possess interdisciplinary skills, uniting classic mechatronics qualifications with sound IT knowledge and high levels of social competence. The transformation of the work environment will change the job profiles and therefore requires employees to be outfitted with a wide range of competencies. To successfully get through the transformation towards I4.0, a definition of the competencies for I4.0 is presented in chapter 7 and compiled in the I4.0 competency framework.

6 Categories of Competences for Key Enabling Technologies

1 Technical	2 Quality, risk & safety	3 Management & entrepreneurship	4 Communication	5 Innovation	6 Emotional intelligence
competences related to practical subjects based on scientific principles (e.g. characterisation, systems integration, mathematical modelling and simulation, top-down fabrication etc.)	competences related to quality, risk & safety aspects (e.g. quality management, computer-aided quality assurance, emergency management and response, industrial hygiene, risk assessment etc.)	competences related to management, administration, IP and finance (e.g. strategic analysis, marketing, project management, IP management, deal negotiation skills etc.)	competences related to interpersonal communication (e.g. verbal communication, written communication, presentation skills, public communication, virtual collaboration etc.)	competences related to design and creation of new things (e.g. integration skills, complex problem solving, creativity, systems thinking)	ability to operate with own and other people's emotions, and to use emotional information to guide thinking and behaviour (e.g. leadership, cooperation, multi-cultural orientation, stress-tolerance, self-control etc.).

Figure 9: 6 Categories of Competences for Key Enabling Technologies

Source: http://skills4industry.eu/sites/default/files/2020-03/Curriculum-%20Guidelines-Final-Report.pdf

As the basis of knowledge graduates must bring domain-related competencies as well as the ability to apply expertise and use technology. In this area, all graduates need to bring IT and I4.0 technology affinity and while working with engineers from different groups, graduates should understand the integration of heterogeneous I4.0 technologies, gain knowledge about mobile technologies and embedded systems and sensors, knowing network technology and M2M communication as well as possess knowledge of robotics and artificial intelligence. On the other hand, IT and IS graduates should both bring modeling and programming knowledge, knowledge about cloud computing and cloud architectures, in-memory DB knowledge, and statistics. For all I4.0 graduates, big data and data analysis and interpretation will be of big importance.,

I4.0 graduates should know service orientation and product service offerings, business process, and change management. They should know about digital security, including data and networks. Economics knowledge and being able to extract business value, a focus on business strategy, always changing business models and entrepreneurship are important skills all graduate programmes should offer.

Communication is one of the key competencies required from graduates. By putting the communication competency in relation with other competencies like literacy and technical communication, intercultural competency, or presentation ability, social skills like collaboration, compromising, and negotiating combined with emotional intelligence will play a key role in I4.0. Since they also play an important aspect in teamwork, project management, and management ability, customer orientation, maintaining customer relationships, and creating business networks, they should be part of each I4.0 curriculum design.

Work and collaboration will become more complex, therefore I4.0 requires graduates to analyze competencies like problem-solving, optimization, analytical skills, and cognitive abilities. To be able to coordinate these competencies, being able to manage complexity and abstraction ability are crucial. Graduates in I4.0 should bring leading and deciding competencies like decision making, taking responsibility, and leadership skills, which should be combined with a set of principles and values with competencies like respecting ethics, environmental awareness, and awareness for ergonomics.

6 EXAM 4.0 Competence Model

To develop an EXAM 4.0 model of required competences and skills for employees working in an advanced manufacturing environment, the structure and results of ESCO and PwC EU Services' KETs Initiative were taken into account. As the model presented below shows, the categories of competences for Key Enabling Technologies were maintained, although the categories were extended by competences of "The Industry 4.0 competency model". This latter model also referred to as Prifti Model, describes competences for employees of the AM, without defining skills for certain jobs or competences for certain companies. The hierarchically structured model displays an extensive list of competences concerning three occupational areas: information systems, computer science, and Engineering. The majority of the behavioural competencies are pertinent to all three occupational areas, whereas only a few competences refer to just one or two areas. Those few competences concern the competency dimension of "applying expertise and technology". As a result, the model demonstrates the development of working conditions in the future, which are expected to evoke an increase of an interdisciplinary approach and non-technical competences or soft-skills. The EXAM 4.0 Competence Model for employees in advanced manufacturing implies the same six categories as the KETs initiative including categories of competences regarding:

- Technical subjects
- Quality, risk and safety
- Management and Entrepreneurship
- Communication
- Innovation
- Emotional Intelligence

The first category refers to the technical competences required of employees working in an advanced manufacturing environment. Similar to the KETs model, this category implies competences concerning design methods, systems analysis, modeling and simulation, ICT skills, computer skills, programming, coding as well as computational thinking. However, the EXAM 4.0 model does not include all listed competences although it summarizes certain competences and skills, for example, competences in STEM (science, technology, engineering, mathematics). The majority of competences are also listed in the Prifti model. Furthermore, this model indicates competences pertaining to Big Data, data analytics, and interpretation, which were added as "data management" competences. Moreover, in the competency dimension of applying expertise and technology, the Prifti model cites different technologies such as embedded systems, sensors, mobile technology, Cloud Computing, robotics, and AI (Artificial Intelligence). The listed technologies refer to certain occupational areas. For this reason, the ability to interact with human-machine-interfaces was included in the EXAM 4.0 model.

The category of quality, risk, and safety implies competences such as quality management, risk assessment, health and safety, industrial hygiene, equipment safety as well as emergency management and response. Furthermore, the competence concerning data security was also added to this category. The issue of data security becomes more important due to the increasing number of smart systems and technologies introduced in companies to save, provide and analyze information. To prevent internal information, competences concerning data security will be decisive in an advanced manufacturing environment.

Management and entrepreneurship present another category of competences required in Advanced Manufacturing. Similar to the KETs model, this category implies competences such as strategic analysis, technology strategy, teamwork skills, marketing, project as well as time and risk management. In addition, change management and customer orientation, both listed in the Prifti model, were also included.

The fourth category concerning communication competences of the PwC EU Service study already implies required competences regarding the interpersonal exchange of information. This category includes competences regarding verbal as well as written and public communication. Competences such as presentation skills and virtual collaboration demonstrate increasing importance. It is expected that the developments and changes caused by Industry 4.0 result in new forms and models of collaboration for employees. For example, working teams of the future are anticipated to be more interdisciplinary and will be working irrespective of location due to the ongoing globalisation and more complex problems referring to several departments.

Similar to competences for KETs, the category of innovation implies competences concerning integration, continuous experimentation, complex problem-solving as well as creativity. In the competency dimension of “Creating & Innovation”, the Prifti model also indicated the ability of critical thinking and abstraction.

The last category, emotional intelligence, implies competences such as adaptability, self-discipline, self-control, continuous improvement, attention to detail, leadership, cooperation as well as the ability to thrive through failures and decision making. Furthermore, several competences of the Prifti model were also integrated into this category, for example, work-life balance, responsibility, flexibility, self-management, and the ability to collaborate with others. Intercultural competences and the ability to work in an interdisciplinary environment, displayed in the Prifti model, substitute and complement the term of multicultural/global orientation, included in the KETs model.

Based on the results and structure of ESCO and KETs initiatives, the EXAM 4.0 model of required competences and skills for employees working in an advanced manufacturing environment also differentiates between general and specific competences. This differentiation concerns technical competences as well as competences in management and entrepreneurship. Regarding the category of technical subjects, general competences refer to all employees working in an advanced manufacturing environment independently of their job profiles, domains, or qualifications. Special competencies of this category refer to certain job profiles or domains, for example, lab skills, scalability, or life-cycle analysis. Furthermore, competences concerning computer-aided-design (CAD) or -engineering (CAE) do not apply to all employees working in the AM. This software is predominantly used by engineers and professionals of specific domains and therefore classified as "special competence".

Concerning competences concerning management and entrepreneurship, the differentiation does not refer to specific domains rather qualifications. Special competences imply management of personal or financial resources as well as deal negotiation skills and management of intellectual property. As a result, employees with an EQF level of six or higher, usually working in middle or higher management and presenting managerial responsibility, are required to occupy certain special competences whereas employees without management function (EQF level of four) do not have to present specific but general competences of management and entrepreneurship.

	TECHNICAL	QUALITY, RISK & SAFETY	MANAGEMENT	COMMUNICATION	INNOVATION	EMOTIONAL INTELLIGENCE
GENERAL COMPETENCIES	Knowledge in STEM ICT skills Programming Coding Computer skills Design methodology Systems analysis Data management skills Ability to interact with human-machine interfaces Interdisciplinary understanding (processes/ technologies / organisations) Manufacturing skills Modelling & simulation	Quality management Health & security Industrial hygiene Equipment safety Emergency response & management Data security ethics	Strategic analysis Analytical thinking Technology strategy Marketing Customer orientation Project Management Time Management Teamwork & ability to work in interdisciplinary environments Change management Risk management Leadership	Interpersonal skills Verbal communication Written communication Presentation skills Public communication Virtual collaboration Ability to deal with conflicts	Integration skills Continuous experimentation Complex problem solving Creativity Abstraction ability Critical thinking Transfer skills Collaborative thinking	Flexibility & Adaptability Responsibility Stress tolerance Ability to thrive on failures Work-life balance Self-control & discipline Decision making Mindset towards lifelong learning & continuous improvement Self management & organisation Cooperation & collaboration skills Intercultural competencies Structured & systematic working approach
SPECIFIC COMPETENCIES	Life cycle analysis Scalability analysis Specific lab skills Computer aided manufacturing/ engineering		Management of Personal resources Management of financial resources IP management Deal negotiation skills			

Figure 10: Exam 4.0 Competence Framework

7 Analysing and Anticipating Skills

Skills anticipation enables training providers, young people, policy-makers, employers, and workers to make better educational and training choices, and through institutional mechanisms and information, resources lead to improved use of skills and human capital development. Individuals, businesses, training organizations, and governments all have to make decisions about what education and training investments they need to take now to maximize the future return on those investments. This means assessing the prospects of the labour market and the potential imbalance between the demand for and supply of skills. There is no one agreed definition of skills needs anticipation, and the term is often used interchangeably with “early identification of skills needs”, “skills needs assessment” or “forecasting”.

In a broad sense, skills need anticipation refers to **activities to assess future skills needs in the labour market in a strategic way, using consistent and systematic methods.**

DEVELOPMENT OF SURVEY METHODOLOGY ON DETECTION OF SKILLS AT SECTORAL LEVEL

There are several foresight methods described in CeDeFop[1,2] that can be selected or combined. The focus in this section is on describing the most appropriate methods of foreseeing skill needs, based on research by the European Network for Foresight Monitoring of the European Commission in 2009, and their characteristics and advantages and disadvantages.

A combination of methods is selected from this overview and adapted to the given requirements. The basic principle method to gain understanding for a future scenario is shown in figure 11.

Utility of skills at sectoral level

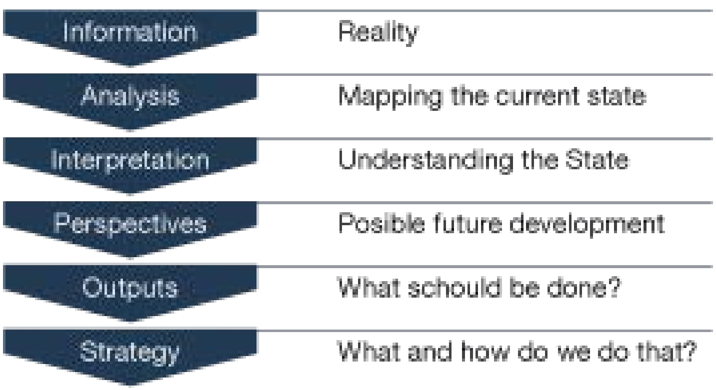

Figure 11: Principal strategy to gain a future scenario

1: https://www.cedefop.europa.eu/

2: https://www.cedefop.europa.eu/files/2219_en.pdf

Objectives of Skills of Sectoral Level

It must be clarified, what purpose the survey should serve and what expectations are placed on the results of the survey. The overriding goal of an employee survey is to get to know the perspective of the person involved and to understand it as precisely as possible.

Motivation	A Worker with skills will have a higher motivation
Career	Skills help in making a career
Remuneration	With skills higher pay can be achieved
Innovation	Exploring new technologies, business cases and products
Value creation and sustainability	Skills can add value and improve sustainability as well as in adopting and using existing technologies

Current Situation on Sectoral Level

A preview of the future should be made based on the current situation. For this future we want to consider the scenario of advanced Manufacturing. The following key points are important:

- The change is already underway
- There is a future scenario for Industry 4.0 and advanced manufacturing
- The forecast for scenarios must be mapped backwards to the requirements of the training
- There are several perspectives: company, school, teacher, plus society with government
- Not too many methods should be used.

It is advisable to combine methods that allow a forecast, that implement a metric and thus allow a measurement or evaluation, and methods to draw conclusions about the training

Forward: Focus groups and Delphi surveys

Metric: Swot analyse, value analysis, morphological analysis

Conclusions: Back-casting, Scenario Analysis

METHODOLOGY FOR ANTICIPATION SKILLS

The survey methods can be divided into 3 categories: the explorative, supplementary and the normative methods.

- Forecast, Foresight
- Metric, evaluation
- Back-casting[3]
- Specification

All this Methods can be embedded in an Agile system

The following table shows an overview about the Methods listed in CeDeFop and the possible combination of these methods:

Method	**Sustainability for Determination of skill requirement***	**Will be together used with**	**Most important property**
Supplementary Methods			
Literature and statistics overview	++++	Scenario-analysis, Backcasting, Delphi-Method	Evidence-based
SWOT-Analysis	++++	Scenario-analysis, Expert panel, Delphi-Method	List factors Effects on the problem
Brainstorming	++++	Expert panel, Delphi-Method	Can reveal unexpected developments
Focusgroup	++++	Scenario-analysis	Improve or generate ideas
Exploratory Methods			
Expert Panel	+++++	Scenario-analysis, Brainstorming, SWOT-Analysis	Evidence for prioritizing of factors
Delphi-Method	+++++	Literature and statistics overview, Brainstorming, SWOT-Analysis	Recognizer the unexpected
Horizontscan	+++	Scenario-analysis	Identify future challenges and trends
Scenario-analysis	+++++	Literature and statistics overview SWOT-Analysis, Roadmapping	Recognizer the unexpected
Cross-Impact-Analysis	++	Literature and statistics overview, Delphi-Method	Evaluates the probabilities of events
Normative Method			
Backcasting	+++	Literature and statistics overview	Offers a clear path into the future
Morphological Analysis	++	Scenario-analysis	Identifies important factors
Roadmapping	+++	Scenario-analysis, Brainstorming, Expert panel	Offers a clear path into the future

*Reference from case studies; The more + the better the method is suitable for anticipation. A maximum of five+

Table 1: survey Methods.

[3] https://en.wikipedia.org/wiki/Backcasting

Analyses of Different Methodologies – Pros and Cons

Survey Methods [4,5,6]

- Questionnaires
- Interview (presence, online, telephone)
- Workshop, Focus group
- Documentation review

Pros:

- Surveys can be conducted faster and cheaper compared to other methods of primary data collection such as observation and experiments
- Primary data gathered through surveys are relatively easy to analyse
- Interview can provide a very specific view of reality
- The workshop and focus group can be carried out in a more standardized manner than individual interviews and generally provide an opinion that is capable of reaching consensus
- Documentation review can be carried out with little effort. The number of sources required is relatively small.

Cons:

- In some cases, unwillingness or inability of respondents to provide information
- Human bias of respondents, i.e. respondents providing inaccurate information
- Differences in understanding: it is difficult to formulate questions in such a way that it will mean exactly same thing to each respondent
- Interviews are very time-consuming to carry out and evaluate
- The preparation of the workshop and focus group is time-consuming. The evaluation is easier than with interviews and almost as simple as with surveys
- The Documentation review depends heavily on the sources selected and only contains information from the past. There is always a time delay.

One way to classify methods is to consider them skills, statements, expertise, interaction, or creativity. These attributes are the building blocks of foresight diamond. The foresight diamond shows which Attributes dominate a certain method. He describes methods from the Perspective of how they are created and developed. For example, creating Scenarios is a very creative activity. Hence, it is close to the climax of the to find creativity. The closer the method to a peak of the diamond the more dominant a certain attribute is. In the middle of the diamond there are methods that have a mixture of several attributes. Certain attributes overlap and combine differently Proportions in each method.[7]

The illustration on the following page shows the Foresight Diamond, as well as the methods described later.

[4] https://en.wikipedia.org/wiki/Survey_methodology

[5] https://research-methodology.net/research-methods/survey-method/

[6] http://joophox.net/papers/SurveyHandbookCRC.pdf

[7] Vgl. Leitfaden zum Vorwegnehmen und Anpassen von Fähigkeiten und Jobs. Band 2: Entwicklung von Vorausschau, Szenarien und Prognosen, Seite 31.

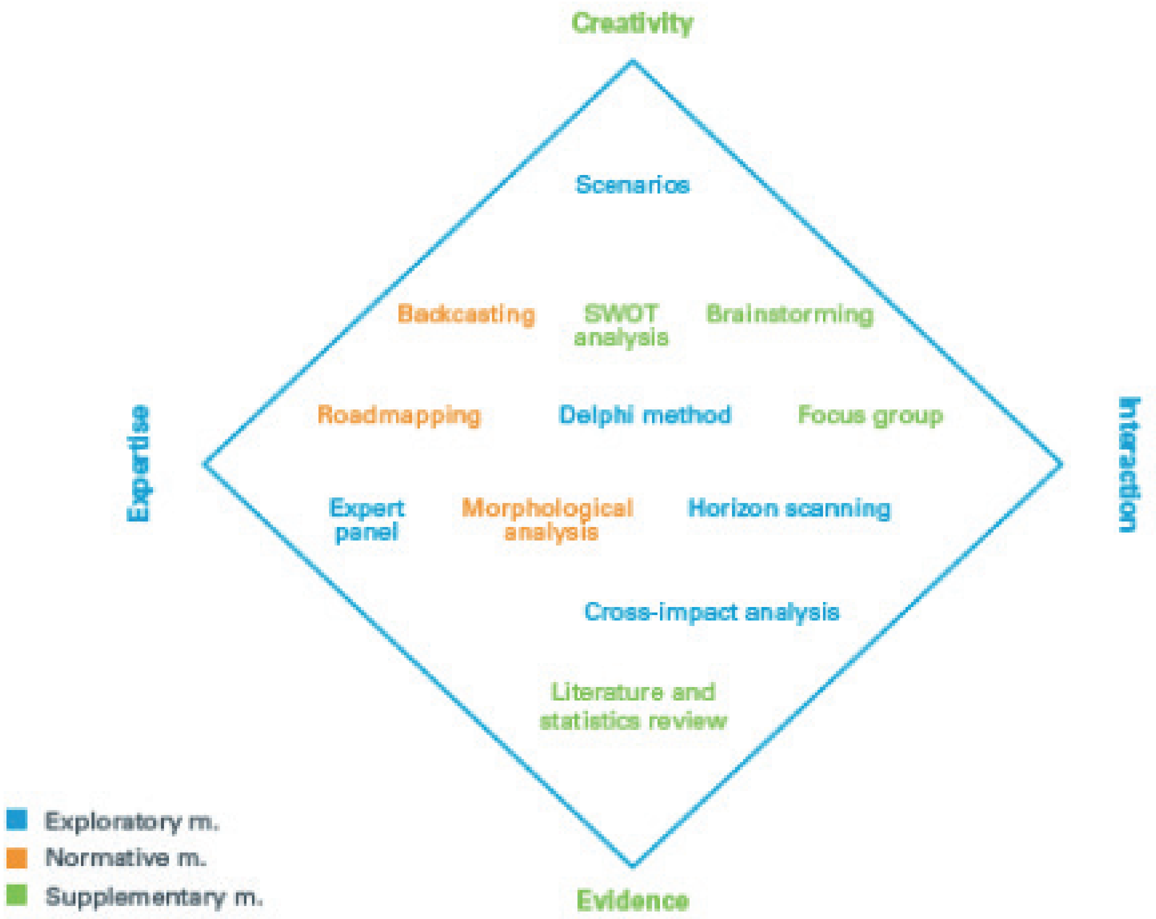

Figure 12: Foresight Diamond[8].

Foresight Methods, Explorative Method

Foresight methods offer many ways to get information about possible to collect future results. There are 3 categories, the exploratory, complementary and normative methods. The exploratory methods start in the present and try to find out where events and trends could lead by saying "What if?" Investigate scenarios[9]. This means that exploration methods [...] with the pre-existing conditions, beliefs and social or technological possibilities begin[10]. These kind of exploration methods are especially useful when no consensus has been reached on the vision[11].

[8] https://www.cedefop.europa.eu/files/2216_en.pdf

[9] Vgl. JRC-IPTS, For-Learn online foresight guide: methodology: exploratory versus normative methods http://forlearn.jrc.ec.europa.eu/guide/4_methodology/meth_explo-norma.htm.

[10] Magnus, 2012

[11] Vgl. JRC-IPTS, For-Learn online foresight guide: methodology: exploratory versus normative methods http://forlearn.jrc.ec.europa.eu/guide/4_methodology/meth_explo-norma.htm.

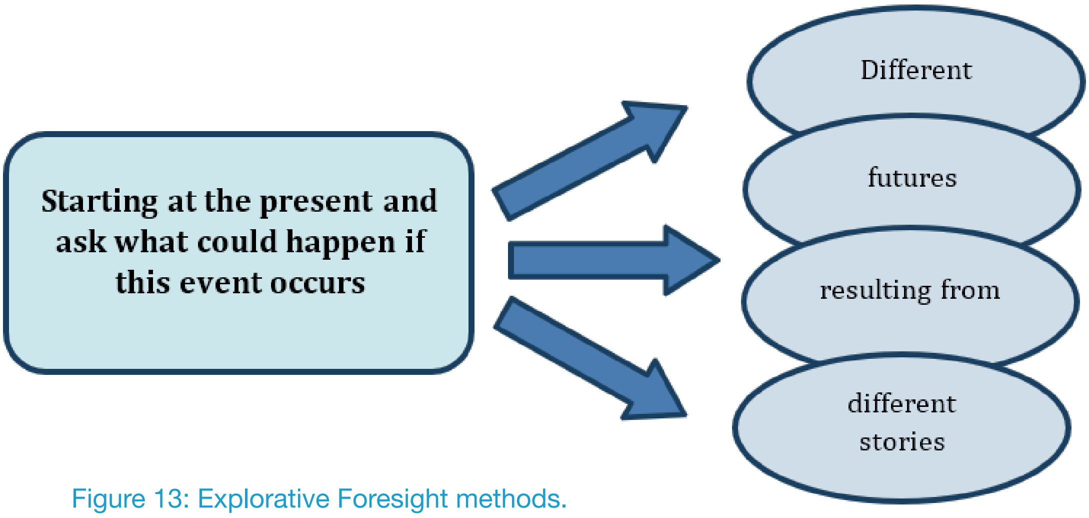

Figure 13: Explorative Foresight methods.

Foresight Methods, Normative Methods

These start with a vision, i.e. a possible or desirable one Future and work backwards to see if and how this future is faced by the existing restrictions of e.g. Skills, resources or Technologies could be achieved or avoided. Normative methods are more effective when a widespread vision already exists.[12]

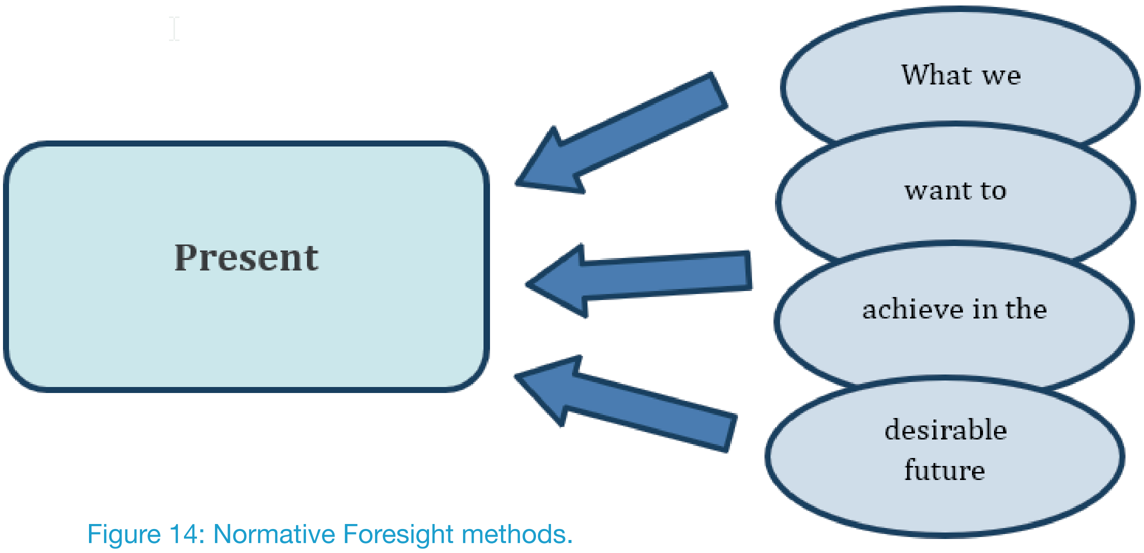

Figure 14: Normative Foresight methods.

[12] Vgl. JRC-IPTS, For-Learn online foresight guide: methodology: exploratory versus normative methods http://forlearn.jrc.ec.europa.eu/guide/4_methodology/meth_explo-norma.htm.

Online Focus Groups

Online Focus Groups[13] are virtual online discussions to probe customer behaviour and preferences. Online focus groups offer the following advantages:

- Cost savings with the savings of facilities and food expenses
- Elimination of travel expenses
- Savings with the high cost of transcripts
- Rapid recruitment of respondents Ease of simultaneous translations

First of all, suitable participants should be identified. These can all come from one area or a combination of different types of stakeholders. The focus should be on a limited number of key questions, moving from the general to the specific. The moderator has a significant role to play in keeping the discussion on track and making sure that every participant is heard. The meeting should then be summarized, analysed and the final report drawn up.

Careful and systematic analysis of the discussions provides information on how the discussed topic is perceived by the group and what could possibly be done better.

Procedure of a meeting

Introduction

Presentation of the Project, Introduction of the participants

Online Panel Discussion

The meetings should be joined by 3 to 5 Participants in the discussion and the Moderator

Keep sessions short

No one will effectively follow more than 1 to 2 hours of online sessions per day. Preferably, reduce the session length to 90 min blocks and include presentation and discussion.

[13] https://www.sisinternational.com/solutions/focus-groups/online-focus-groups/, https://www.slideshare.net/sisinternationalresearch/virtual-focus-groups-online-nationwide-and-worldwide, https://www.b2binternational.com/research/methods/faq/what-is-an-online-focus-group/

Back-casting is a strategic planning tool in which the first step is to define how the future will be in e.g. 20 years. In the second step, it is then analysed which strategic measures and methods can be used to achieve this future state.

Back-casting reminds participants that the future is not linear and can have many alternative outcomes depending on the decisions made and the impact of external events on an organization. The following figure shows the back-casting procedure in a simplified manner.

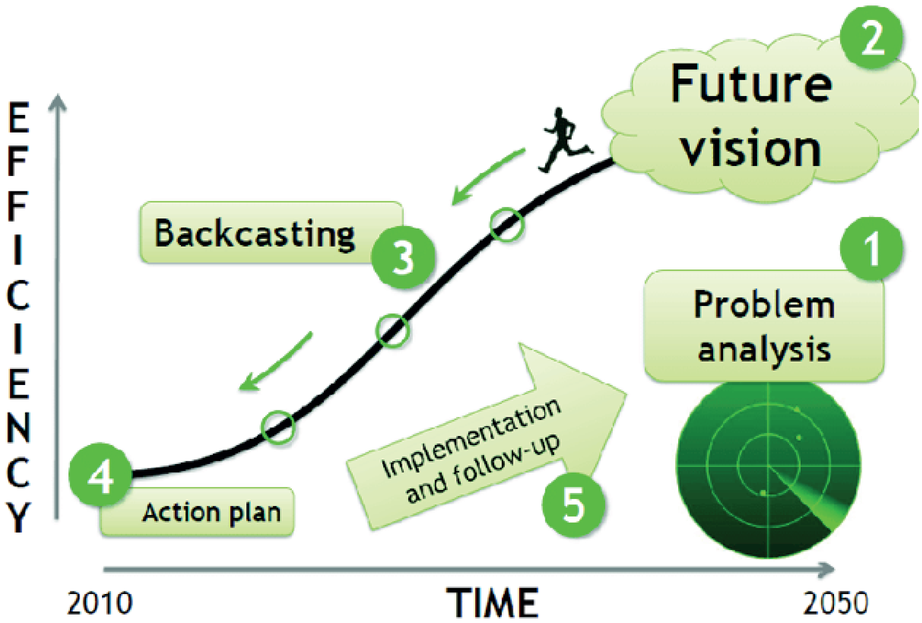

Figure 15: Workflow Back-casting Method

Back-casting involves several actions that are required to achieve a desired output.

It is important to involve the stakeholders in the process at an early stage and to develop a future long-term vision of the desired scenario. Once the collective desirable vision is developed, alternative paths are suggested and examined for possible advantages and disadvantages, bottlenecks and problems.

Stakeholders then choose a path, formulate a plan of action that defines their roles, and commit to them.

Designing the future by designing today's action is one of the most significant advantages of this method. The disadvantage of this method is that it is assumed that the desirable future will occur. In addition, back-casting is resource-intensive and may need constant updates.

[14] Vgl. https://www.researchgate.net/figure/Steps-in-backcasting_fig1_334312079

[15] Vgl. Leitfaden zum Vorwegnehmen und Anpassen von Fähigkeiten und Jobs. Band 2: Entwicklung von Vorausschau, Szenarien und Prognosen, Seite 54.

Principle Basic Method

As a basic procedure, it is recommended to use an empirical method for foresight and to reflect it back with a normative method. The review or metric is already included in both methods. Therefore, it is not necessary to implement a special method for measurement.

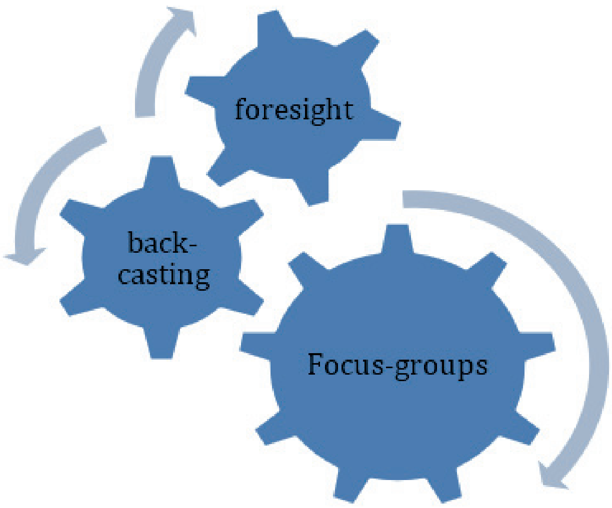

Figure 16: Interaction of foresight and back-casting method with Focus-groups

Combining two approaches in a cyclic process model

- Exploratory methods
- Normative methods

Predict ◄▬► Correct procedure

Focus-groups ◄▬► Back-casting

The consequence is an Agile Method.

BMBF foresight is characterised by combining the two approaches in a cyclic process model: a cycle strongly influenced by the technology-push approach follows a cycle that is mainly demand-pull oriented, and vice versa. In this way, the results of each preceding cycle can be evaluated and further developed in the subsequent cycle from an alternative perspective.

Step 1: **PREDICT**

Based on the discussion result of a Focus-groups or a comparable method the future will be predicted.

Step 2: **CORRECT**

Resulting from the Contradictions the scenario will be adjusted with the back-casting method

Step 3: **MANAGE**

Repeat the predict correct loop until the result is suitable (agile Method)

As a second pillar agile methods should be used with its central corner points:

Agile Methode[16]

- Task Board: Overview of current tasks
- Use Cases: Describe use cases and requirements from the customer's point of view
- Daily-Standup-Meetings: Efficient status meetings, daily meetings while standing (in one survey loop)
- Work-in-Progress-Limits (WIP-Limits): Limitation of parallel tasks to maintain productivity
- Burn-Down-Charts: Visualization of the work status
- Timeboxing: (Really) fixed time constraints
- Planning Poker: Dynamic method for estimating costs
- Business value: Generation of customer benefits as early as possible
- Definition of Done: Clear definition of when a task is considered completed
- Osmotic communication: Establish the same level of information
- Earned Value: Progress and budget control
- Story Points: metric for cost estimates
- Epic: Summarizing related use cases
- Persona: Take the customer's perspective

The application of agile methods is expedient[17]

Based on the Agile Manifest[18] and Focus groups[19]

Based on a questionnaire, characteristics should be determined qualitatively and quantitatively. The main objective is to be able to translate these results into concrete strategies.

16 https://www.haufe.de/personal/hr-management/agile-methoden-definition-und-ueberblick_80_428832.html
17 https://age-of-product.com/remote-agile-survey/
18 https://www.projektmagazin.de/glossarterm/agiles-manifest-agile-manifesto
19 https://methods.sagepub.com/book/focus-groups-as-qualitative-research/n2.xml

Detect problem → Generate data → Analyse data → Provide solutions

Possible methodology:

- Estimate future Situation
- Find Gap to existing and planned activities
- Find selective Requirements for new activities
- Define framework for closing the Gap

SKILLS AT SECTORAL LEVEL

The benefits of skills at sectoral Level are listed in the referenced documents [20,21]. It shows how skills at the sectoral level have a decisive influence on the innovative capacity of companies. A company becomes adaptable through adapted skills of the employees. Only companies with well-trained and high skilled employees can be competitive.

To realize a survey, the following Workflow is recommended.

[20] https://www.tandfonline.com/doi/full/10.1080/09645292.2018.1515309
[21] https://onlinelibrary.wiley.com/doi/full/10.1111/bjir.12503

Process Flow for the Survey

Prepare the Survey

- Create the questionnaire
- Prepare an interview guide with Timetable
- Select the participant group

Experts from different sectors of the I4.0

- Leaders CEO, CTO
- Experts (Head of …)
- Organisations Chambers and University's
- VET Trainer, employees

Deploy and conduct the survey

- Questionnaire
- Short interview (present tense, online via Zoom, WebEx, ...)
- Focus-group Online

Problems

- Find a common time slot for at least 3 participants
- Leak of knowledge in all different aspects

Special advantages

- Different perspective to AM4.0
- Real discussion to get the maximum of knowledge

8 Conclusion

The main output of the WP2 research is the EXAM 4.0 framework for assessing the training needs or the work-readiness of the learners taking into account different industry 4.0 relevant aspects and therefore it should be multidimensional. We are proposing to employ four different dimensions to defining the educational needs. Within that context, the goal of this report is to identify the related relevant issues for the subsequent curricula design and project activities, such as the lab design or the learning factory. Second, the report had a focus on the skills required for succeeding in the Industry 4.0 environment as described in the EXAM 4.0 framework, the efforts on the different regions in terms of education, up/reskilling the workforce, and a comparison of their educational/technological maturity and challenges through a mixture of desk and field research.

The two EXAM frameworks will serve as one of the two cornerstones to build a blueprint for future education, the other one being a benchmark on state-of-the-art education initiatives in work-based learning environments such as I4.0 labs and learning factories, which will be the focus of the subsequent research done in the EXAM 4.0 advanced manufacturing workshop 4.0 VET 4.0 for AM reports.

THE EUROPEAN QUALIFICATION FRAMEWORK (EQF) AND INDUSTRY 4.0

The European Qualification Framework could be described as a ‘meta-framework’ designed to promote both a common terminology and common reference points for the comparison of the qualifications of the member countries of the EU (see Coles, 2007; Bjornavold & Coles, 2008; Markowitsch & Luomi-Messerer, 2008).

The EQF focuses on learning outcomes: what a person, holding a particular qualification, actually knows and is able to do. This approach is intended:

- to support a better match between the needs of the labour market (for knowledge, skills and competences) and education and training provision
- to facilitate the validation of non-formal and informal learning
- to facilitate the transfer and use of qualifications across different countries and education and training systems.

The eight levels of reference are described in terms of learning outcomes. The EQF recognizes that European education and training systems are so diverse that **only learning outcomes allow comparisons and enable cooperation between countries and institutions.**

	Knowledge	Skills	Responsibility and autonomy
	In the context of EQF, knowledge is described as theoretical and/or factual.	In the context of EQF, skills are described as cognitive (involving the use of logical, intuitive and creative thinking) and practical (involving manual dexterity and the use of methods, materials, tools and instruments).	In the context of the EQF responsibility and autonomy is described as the ability of the learner to apply knowledge and skills autonomously and with responsibility.
LEVEL 1 The learning outcomes relevant to Level 1 are:	Basic general knowledge	Basic skills required to carry out simple tasks	Work or study under direct supervision in a structured context
LEVEL 2 The learning outcomes relevant to Level 2 are:	Basic factual knowledge of a field of work or study	Basic cognitive and practical skills required to use relevant information in order to carry out tasks and to solve routine problems using simple rules and tools	Work or study under supervision with some autonomy
LEVEL 3 The learning outcomes relevant to Level 3 are:	Knowledge of facts, principles, processes and general concepts, in a field of work or study	A range of cognitive and practical skills required to accomplish tasks and solve problems by selecting and applying basic methods, tools, materials and information	Take responsibility for completion of tasks in work or study; adapt own behaviour to circumstances in solving problems
LEVEL 4 The learning outcomes relevant to Level 4 are:	Factual and theoretical knowledge in broad contexts within a field of work or study	A range of cognitive and practical skills required to generate solutions to specific problems in a field of work or study	Exercise self-management within the guidelines of work or study contexts that are usually predictable, but are subject to change; supervise the routine work of others, taking some responsibility for the evaluation and improvement of work or study activities

	Knowledge	Skills	Responsibility and autonomy
LEVEL 5 The learning outcomes relevant to Level 5 are:	Comprehensive, specialised, factual and theoretical knowledge within a field of work or study and an awareness of the boundaries of that knowledge	A comprehensive range of cognitive and practical skills required to develop creative solutions to abstract problems	Exercise management and supervision in contexts of work or study activities where there is unpredictable change; review and develop performance of self and others
LEVEL 6 The learning outcomes relevant to Level 6 are:	Advanced knowledge of a field of work or study, involving a critical understanding of theories and principles	Advanced skills, demonstrating mastery and innovation, required to solve complex and unpredictable problems in a specialised field of work or study	Manage complex technical or professional activities or projects, taking responsibility for decision-making in unpredictable work or study contexts; take responsibility for managing professional development of individuals and groups
LEVEL 7 The learning outcomes relevant to Level 7 are:	Highly specialised knowledge, some of which is at the forefront of knowledge in a field of work or study, as the basis for original thinking and/or research Critical awareness of knowledge issues in a field and at the interface between different fields	Specialised problem-solving skills required in research and/or innovation in order to develop new knowledge and procedures and to integrate knowledge from different fields	Manage and transform work or study contexts that are complex, unpredictable and require new strategic approaches; take responsibility for contributing to professional knowledge and practice and/or for reviewing the strategic performance of teams
LEVEL 8 The learning outcomes relevant to Level 8 are:	Knowledge at the most advanced frontier of a field of work or study and at the interface between fields	The most advanced and specialised skills and techniques, including synthesis and evaluation, required to solve critical problems in research and/or innovation and to extend and redefine existing knowledge or professional practice	Demonstrate substantial authority, innovation, autonomy, scholarly and professional integrity and sustained commitment to the development of new ideas or processes at the forefront of work or study contexts including research

Source: "Descriptors defining levels in the European Qualifications Framework (EQF), European Commission.
https://ec.europa.eu/ploteus/fr/node/1440

RESEARCH ON COMPETENCY MODELS

Competency, as defined, is a set of **knowledge, skills, and attitudes** that enable an individual to perform the activities of a given job or occupation to or beyond expected standards. Competency frameworks can benefit organizations by enabling them to describe job roles and functions, standardize performance of professionals, define expected performances, and design needs-based education and training programs (Bawane J.; 2015).

Competencies distilled in models are the foundation for important human resource functions such as recruitment and hiring, but also for education, training and development, and performance management. A competency model will help the consortium to identify and illustrate the various stakeholders' views of the field's nature and competencies it requires. Since competencies are gained through learning, competency models do reflect on education and training. The value of a competency model is to examine the competencies that a learner possesses and may still need to perform an I4.0 occupation.

For institutions a competency model provides a visual structure that can be applied to a given study programme and occupation and serve different purposes, including accreditation, curriculum design and development.

Comparison of Competency Models of Industry 4.0 / Advanced Manufacturing

The three models we analyzed are:

- U.S. Department of Labor's *Advanced Manufacturing Competency* Model, the Society of Manufacturing Engineers'
- *Four Pillars of Manufacturing Knowledge*
- *Competency Model for "Industrie 4.0" Employees*

The main findings of the work include a detailed competency model for Industry 4.0 that covers the professional areas of Information Systems, Computer Science and Engineering

While the content in these models has been validated by governmental, industry, and educational stakeholders, less explored is whether these models are readily understandable by their intended audiences and industry stakeholders.

Advanced Manufacturing Competency Model

In 2006, the U.S. Department of Labor (DOL) collaborated with the Employment and Training Administration to develop the Advanced Manufacturing Competency Model. The model was developed with industrial-organizational psychologists, along with leading industry organizations including the Society of Manufacturing Engineers (SME), Manufacturing Institute, National Council for Advanced Manufacturing, National Association of Manufacturers (NAM), and many other industry stakeholders complemented by a few education stakeholders. This model defines the manufacturing skills workers need to be successful in 21st century manufacturing, as shown in Figure 17.

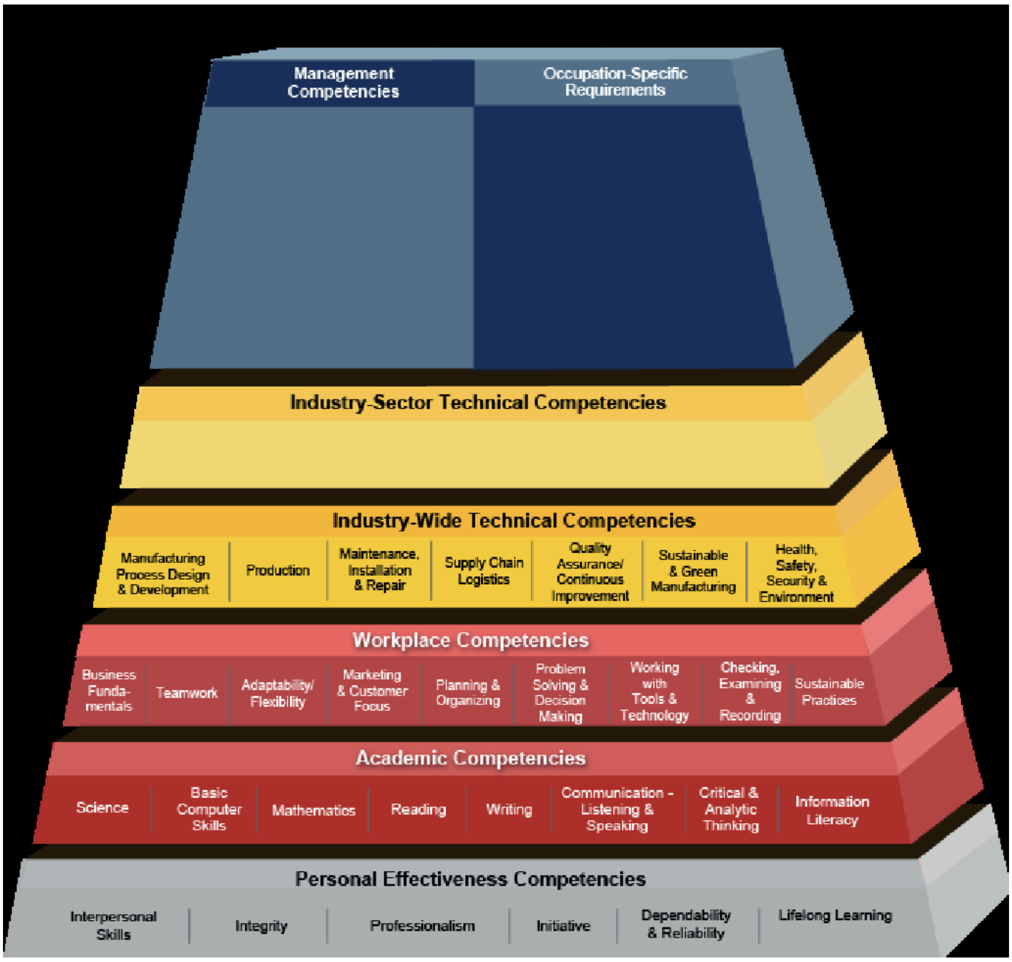

Figure 17: Advanced Manufacturing Competency Model; CareerOneStop. (2010).

First, the *Advanced Manufacturing Competency Model* illustrates how occupational and industry competencies build on a foundation of personal effectiveness, academic, and workplace competencies in a pyramid graphic. Each different level represents the skills, knowledge, and abilities required for successful performance in the Advanced Manufacturing industry at different stages of career. This structure clearly signals the cumulative nature of the skills, knowledge, and abilities essential for successful performance in the Advanced Manufacturing industry.

The Advanced Manufacturing Competency Model is a pyramid graphic with four tiers:

- **TIER 1**: **Personal Effectiveness Competencies** are personal attributes essential for all life roles. Often referred to as "soft skills," personal effectiveness competencies are generally learned in the home or community and honed at school and in the workplace.

- **TIER 2**: **Academic Competencies** are primarily learned in an institution setting. They include cognitive functions and thinking styles. Academic competencies are likely to apply to all industries and occupations.

- **TIER 3**: **Workplace Competencies** represent motives and traits, as well as interpersonal and self-management styles. They are applicable to a large number of occupations and industries.

- **TIER 4**: **Industry-Wide Competencies** cover the knowledge and skills and abilities from which workers across the industry can benefit, regardless of the sector in which they operate. Many of the critical work functions on this tier deal with awareness or understanding (CareerOneStop, 2010).

The Four Pillars of Manufacturing Knowledge

The Four Pillars model was completed in parallel with the comprehensive Society of Manufacturing Engineers (SME) study of manufacturing education called Curricula 2015. The model was developed by SME through its Center for Education and derived from the ABET accreditation criteria for manufacturing engineering programs. It also builds on the topics in the SME body of knowledge for the certification of manufacturing engineers and manufacturing technologists. The model Four Pillars of Manufacturing Knowledge encompasses three variables: **four pillars, two foundations, and 10 major subject areas.** The four pillars are capped with the titles shown on the top for the four major competencies expected of manufacturing engineers and technologists. Moreover, there are two foundations, which show the educational fundamentals on which the manufacturing engineering field is based, including mathematics and science, and the personal effectiveness. Another variable is ten major subject areas, which are arrayed to give more detail to the content included in tertiary degree programs: Engineering Sciences, Materials, Manufacturing Processes, Product Design, Process Design, Equipment/Tool Design, Production System Design, Automated Systems and Control, Quality and Continuous Improvement, and Manufacturing Management.

The model illustrates the four knowledge areas, or “pillars”: 1) Materials and manufacturing processes; 2) Product, tooling, and assembly engineering; 3) Manufacturing systems and operations; and 4) Manufacturing competitiveness (Moet 2017). The systematic structure that has four pillars that rest on a foundation with 10 major subject areas that give more detail to these foundations.

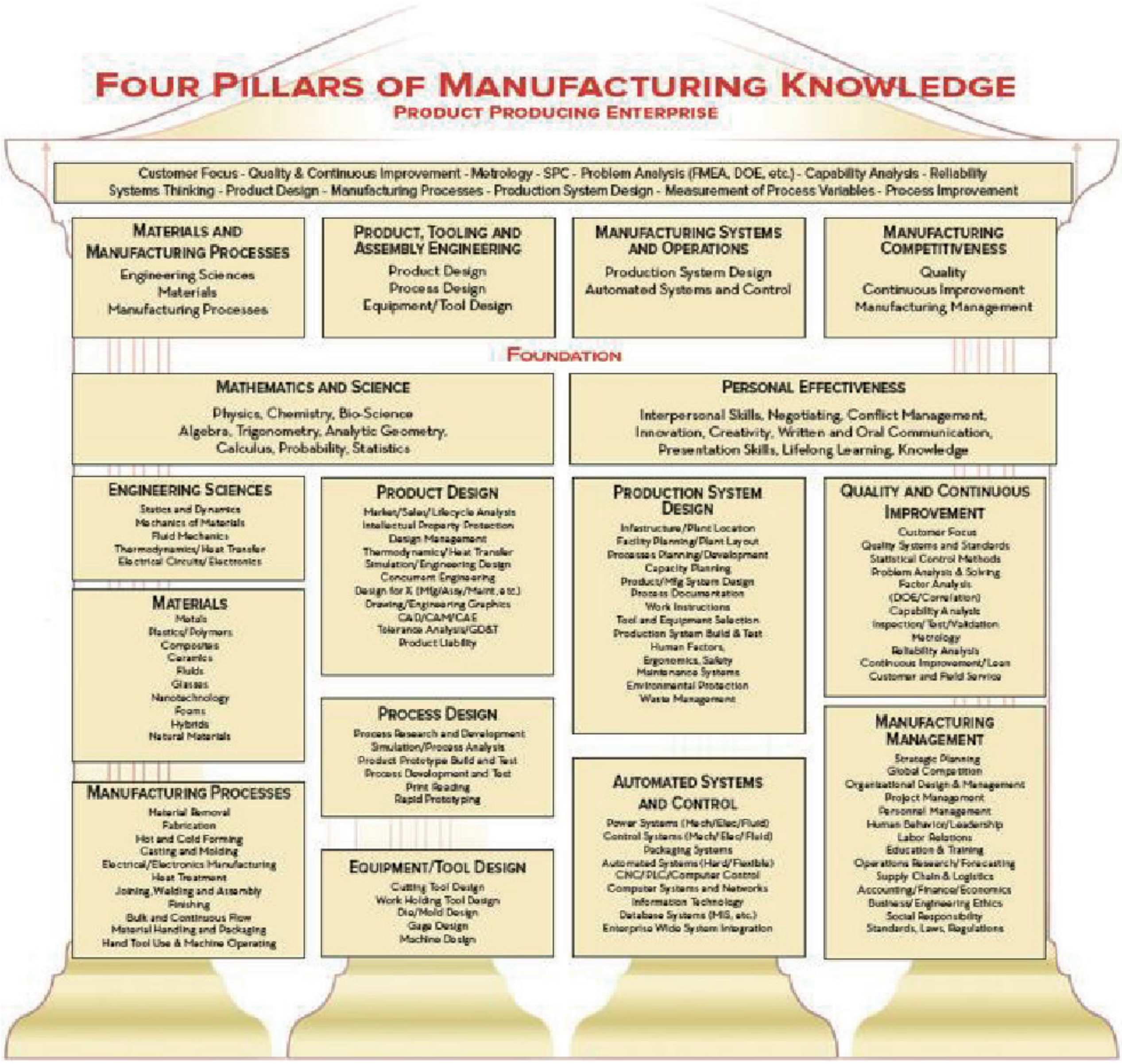

Figure 18 depicts the Four Pillars Model.

Competency Model for "Industry 4.0" Employees

The Industry 4.0 competency model (Prifti, Knigge, Kienegger, et al., 2017), is based on a behavioural oriented approach concerning three variants, namely **Information Systems, Information Technology and Engineering** and is developed by extending the SHL Universal Competency Framework.

The model focuses on the learner as the individual and key enabler for Industry 4.0. It does not focus on defining skills for a certain job profile, or collective competencies for a company. The goal is to define competencies for Industry 4.0 that could be adapted through an appropriate teaching/learning concept.

The model consists of three hierarchical levels, with the first level called “Great Eight”. It describes the eight core factors that underpin job performance. All competencies can be clustered in these eight groups of competencies, followed by 20 competency dimensions that divide these eight groups in further categories, which are separated into 69 I4.0 component competencies.

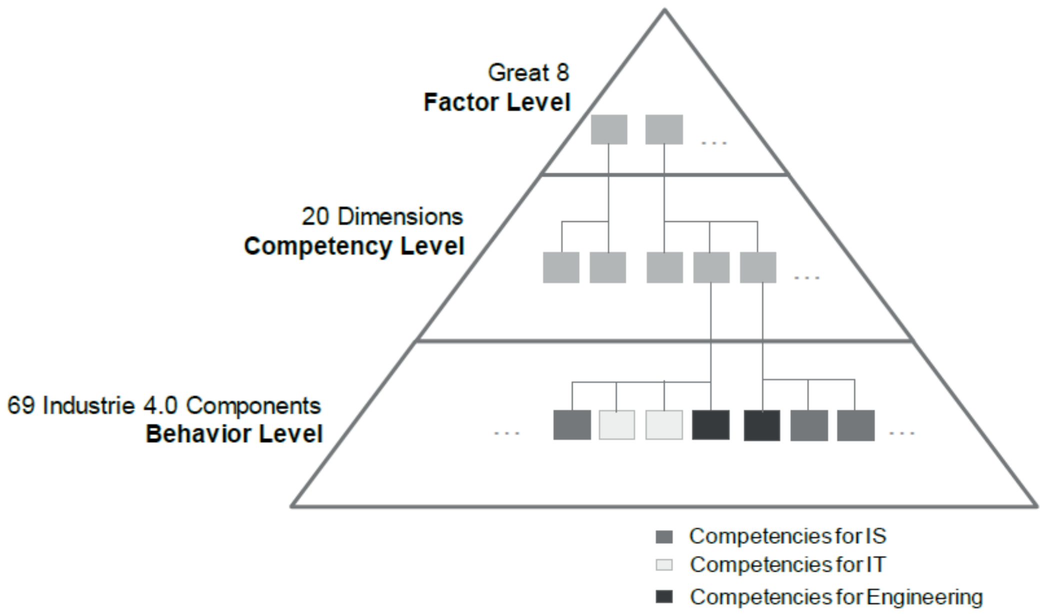

Figure 19: Structure of Competency Model Source: Prifti, L.; Knigge, M.; Kienegger, H.; Krcmar, H. (2017)

The results delivered mostly competencies of behavioural nature that are relevant for all three areas. Only few competencies are related to domain knowledge and can be partly assigned to a certain area as IS, CS and Engineering. This demonstrates a shift in the work of the future, where it will become more interdisciplinary and it is more relevant for professionals to provide behavioural competencies, while the domain related ones will be partly substituted by automatic processes (Prifti 2019).

Competencies, on the other hand, relate to the behaviours underpinning successful performance; what it is people do in order to meet their objectives; how they go about achieving the required outcomes; what enables their competent performance. The competencies defined relate to how knowledge and skills are used in performance, and about how knowledge and skills are applied in the context of some particular set of job requirements in I4.0. The assessment of knowledge and skills is quite different from the assessment of competencies:

- Knowledge and skills are job or occupation specific, and the domain of knowledge and skills across the whole world of work is potentially limitless.

- Competencies are generic in that they apply across several occupations and jobs in I4.0.

The number of competencies is finite and at the level of detail described in the Industrie 4.0 model, relatively small. Competencies determine whether or not people will acquire new job knowledge and skills, and how they will use that knowledge and skills to enhance their performance in the workplace (Bartram, 2011).

REFERENCES

- Buxmann P., Hess T., & Ruggaber R. (Eds.). (2009). *Internet of Services*. SpringerLink.
- Chouhan V.S., & Srivastava S. (2014). *Understanding Competencies and Competency Modeling - A Literature Survey.*
- Christian Burmeister, Dirk Lüttgens and Frank T. Piller (2016). Business Model Innovation for Industrie 4.0: Why the "Industrial Internet" Mandates a New Perspective on Innovation. *Die Unternehmung, 70. Jg.*(2).
- David C. McClelland. (1973). T*esting for Competence RatherThan for* "*Intelligence*". Harvard University.
- Ellis S., Morris H.D., & Santagate J. (2015). *IoT-Enabled Analytic Applications Revolutionize Supply Chain Planning and Execution*.
- Hannola, L., Richter, A., Richter, S., & Stocker, A. (2018). Empowering production workers with digitally facilitated knowledge processes – a conceptual framework. *International Journal of Production Research, 56*(14), 4729–4743. https://doi.org/10.1080/00207543.2018.1445877
- Kagermann, H., Wahlster, W., & Helbig, J. (2013). Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0: Abschlussbericht des Arbeitskreises Industrie 4.0. https://www.bmbf.de/files/Umsetzungsempfehlungen_Industrie4_0.pdf
- Lee, J., Jin, C., & Bagheri, B. (2017). Cyber physical systems for predictive production systems. *Production Engineering*, 11(2), 155–165. https://doi.org/10.1007/s11740-017-0729-4
- Neaga Irina. (2019). *Applying Industry 4.0 and education 4.0 to engineering education*. Canadian Engineering Education Association (CEEA-ACEG19) Conference.

- Obermaier, R. (2019). *Handbuch Industrie 4.0 und Digitale Transformation: Betriebswirtschaftliche, technische und rechtliche Herausforderungen*. Springer Fachmedien Wiesbaden. https://books.google.de/books?id=XuuoDwAAQBAJ

- PricewaterhouseCoopers EU Services EESV. (2020). *Curriculum Guidelines 4.0: Future-proof education and training for manufacturing in Europe.* Executive Agency for Small and Medium-sized Enterprises (EASME). EASME-COSME-ENQUIRIES@ec.europa.eu

- Radziwon, A., Bilberg, A., Bogers, M., & Madsen, E. S. (2014). The Smart Factory: Exploring Adaptive and Flexible Manufacturing Solutions. *Procedia Engineering, 69*, 1184–1190. https://doi.org/10.1016/j.proeng.2014.03.108

- Tao, F., Cheng, Y., Zhang, L., & Nee, A. Y. C. (2017). Advanced manufacturing systems: socialization characteristics and trends. *Journal of Intelligent Manufacturing, 28*(5), 1079–1094. https://doi.org/10.1007/s10845-015-1042-8

- Teichler U., & Schomburg H. (2013). *Analyzing the Results of Study in Higher Education and the Requirements of the World of Work.*

- Wortmann, F., & Flüchter, K. (2015). Internet of Things. *Business & Information Systems Engineering, 57*(3), 221–224. https://doi.org/10.1007/s12599-015-0383-3

- Zack, M., McKeen, J., & Singh, S. (2009). Knowledge management and organizational performance: an exploratory analysis. *Journal of Knowledge Management, 13*(6), 392–409. https://doi.org/10.1108/13673270910997088

- Zhong, R. Y., Xu, X., Klotz, E., & Newman, S. T. (2017). Intelligent Manufacturing in the Context of Industry 4.0: A Review. *Engineering, 3*(5), 616–630. https://doi.org/10.1016/J.ENG.2017.05.015

ONLINE REFERENCES

http://www.foresight-platform.eu/community/forlearn/what-is-foresight/

http://projects.mcrit.com/esponfutures/documents/Foresight%20methodology/Popper%20R.%20(2008)%20How%20are%20foresight%20methods%20selected.pdf

http://www.foresight-platform.eu/community/forlearn/how-to-do-foresight/process/methodology/

http://www.forschungsinfo.de/Archiv/iFQ_Jahrestagung_08/beitraege/popper.pdf

- **Cedefop**

  https://www.cedefop.europa.eu/

- **DEVELOPING SKILLS FORESIGHTS, SCENARIOS AND FORECASTS,2016**

  https://www.cedefop.europa.eu/files/2216_en.pdf

- **DEVELOPING AND RUNNING AN ESTABLISHMENT SKILLS SURVEY, 2017**

  https://www.cedefop.europa.eu/files/2219_en.pdf

- **Backcasting and Survey method from Wikipedia, 2020**

  https://en.wikipedia.org/wiki/Backcasting

  https://en.wikipedia.org/wiki/Survey_methodology

- **Survey Method, BBMR Business Research Methodology**

  https://research-methodology.net/research-methods/survey-method/

- **Edith D. De Leeuw, International Handbook of Survey Methodology“, European Association of Methodology (EAM),2008**

  http://joophox.net/papers/SurveyHandbookCRC.pdf

- **Guide to anticipating and matching skills and jobs. Volume 1: Using labour market information**

  https://www.cedefop.europa.eu/en/publications-and-resources/publications/2215

- **Guide to anticipating and matching skills and jobs. Volume 2: Developing skills foresights, scenarios and forecasts**

  https://op.europa.eu/de/publication-detail/-/publication/77089ba6-b79d-11e6-9e3c-01aa75ed71a1/language-en/format-PDF/source-search

- **JRC-IPTS, For-Learn online foresight guide: methodology: exploratory versus normative methods**

  http://forlearn.jrc.ec.europa.eu/guide/4_ methodology/meth_explo-norma.htm

- **Remote Agile Survey — Let’s Stop Guessing, Join the Study, 2020**

  https://age-of-product.com/remote-agile-survey/

- **Agiles Manifest (Agile Manifesto), 2020**

  https://www.projektmagazin.de/glossarterm/agiles-manifest-agile-manifesto

- **David L. Morgan „Focus Groups As A Qualitative Method“, Sage 1997**

  https://methods.sagepub.com/book/focus-groups-as-qualitative-research/n2.xml

- **Sectoral cognitive skills, R&D, and productivity: a cross-country cross-sector analysis, 2018**

  https://www.tandfonline.com/doi/full/10.1080/09645292.2018.1515309

- **When Do Companies Train Low-Skilled Workers?**

- **The Role of Institutional Arrangements at the Company and Sectoral Level , 2019**

  https://onlinelibrary.wiley.com/doi/full/10.1111/bjir.12503

- **European Commission (2020), About Europass, 2020**

  https://europa.eu/europass/en/about-europass, access on 28th August 2020.

- **European Commission (2020), ESCO Occupation Justice of peace, 2020**

  http://data.europa.eu/esco/occupation/f634ce9b-68a5-4a8a-af4a-ed13fc0deba9, access on 28th August 2020.

- **European Commission (2020), Essential, 2020**

  https://ec.europa.eu/esco/portal/escopedia/Essential, access on 28th August 2020.

- **European Commission (2020), European Skills, Competences, Qualifications and Occupations (ESCO), 2020**

  https://ec.europa.eu/esco/portal/escopedia/European_Skills_44__Competences_44__Qualifications_and_Occupations__40_ESCO_41_, access on 28th August 2020.

- **European Commission (2020), Occupations pillar, 2020**

  https://ec.europa.eu/esco/portal/escopedia/Occupations_pillar, access on 28th August 2020.

- **European Commission (2020), Optional, 2020**

  https://ec.europa.eu/esco/portal/escopedia/Optional, access on 28th August 2020.

- **European Commission (2020), Qualifications pillar, 2020**

  https://ec.europa.eu/esco/portal/escopedia/Qualifications_pillar, access on 28th August 2020.

- **European Commission (2020), Skills pillar, 2020**

  https://ec.europa.eu/esco/portal/escopedia/Skills_pillar, access on 28th August 2020.

- **European Commission (2020), Skill reusability level, 2020**

  https://ec.europa.eu/esco/portal/escopedia/Skill_reusability_level, access on 28th August 2020.

EXAM 4.0

THE EXCELLENT ADVANCED MANUFACTURING 4.0