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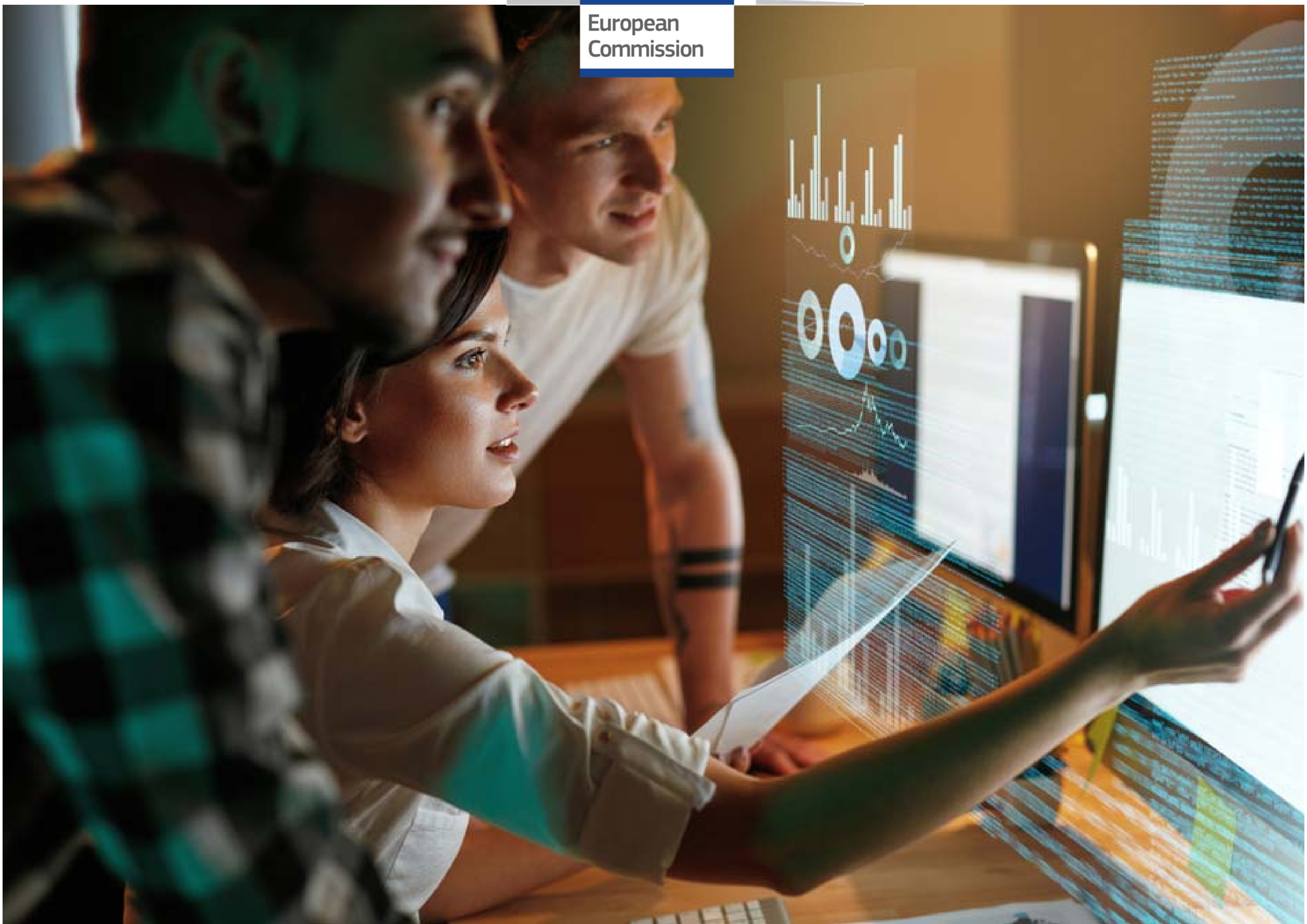

Skills for Industry

Curriculum Guidelines 4.0

Future-proof education and training for manufacturing in Europe

FINAL REPORT

Written by PwC
January 2020

EUROPEAN COMMISSION

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Skills for Industry

Curriculum Guidelines 4.0: Future-proof education and training for manufacturing in Europe

FINAL REPORT

Executive Agency for Small and Medium-sized Enterprises (EASME)
COSME – CURRICULUM GUIDELINES FOR KETS AND AMT
2020

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List of abbreviations

TABLE 0-1: List of abbreviations

Abbreviation	Full text
AI	Artificial Intelligence
AM	Additive Manufacturing
AMT	Advanced Manufacturing Technologies
AR	Augmented Reality
BSc	Bachelor of Science
CAD	Computer-Aided Design
CAGR	Compound Annual Growth Rate
CEDEFOP	European Centre for the Development of Vocational Training
CNC	Computer Numerical Control
DG GROW	Directorate General for Internal Market, Industry, Entrepreneurship and SMEs
EASME	Executive Agency for Small and Medium-sized Enterprises
EC	European Commission
ECTS	European Credit Transfer and Accumulation System
EEA	European Economic Area
EIT	European Institute of Innovation and Technology
EMEA	Europe, the Middle East and Africa
EQAVET	European Quality Assurance in Vocational Education and Training
ERP	Enterprise resource planning
ESN	Erasmus Student Network
EU	European Union
EUR	Euro
FTE	Full-Time Equivalent
GBP	British pound sterling
HE	Higher Education

Abbreviation	Full text
HEI	Higher Education Institution
I4.0	Industry 4.0
IIoT	Industrial Internet of Things
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
KET	Key Enabling Technology
KSG	Key Stakeholder Group
MIT	Massachusetts Institute of Technology
m-learning	Mobile learning
MOOC	Massive Open Online Course
MR	Mixed Reality
MS	Member State
MSc	Master of Science
NIST	National Institute of Standards and Technology
OECD	Organisation for Economic Cooperation and Development
PhD	Doctor of Philosophy
PSS	Product-Service System
QF	Qualification Framework
R&D	Research and Development
SC	Steering Committee
SCADA	Supervisory Control and Data Acquisition
SDGs	Strategic Development Goals
SME	Small and Medium-Sized Enterprises
SPOC	Small Private Online Course
STEAM	Science, Technology, Engineering, Arts and Mathematics
STEM	Science, Technology, Engineering and Mathematics
TF	Teaching Factory

Abbreviation	Full text
UK	United Kingdom
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCO-IBE	International Bureau of Education of the United Nations Educational, Scientific and Cultural Organization
UNIDO	United Nations Industrial Development Organization
US	United States
USD	United States Dollar
VDI	Virtual Desktop Infrastructure
VET	Vocational Education and Training
VR	Virtual Reality
WEF	World Economic Forum
WP	Work Package
WUR	World University Ranking

Executive summary

We are in the age of the Fourth Industrial Revolution. The main challenges are related to the exponential growth of digital tools that include robots, cobots, connected objects, communication systems, data centers and associated energy consumption. The industrial sector must find new technologies, new designs, new architectures, new communication and data storage concepts, in order to increase the performances of the digital world and, at the same time, to minimise the related energy consumption.

Specifically, Europe needs highly skilled, flexible, emotionally and socially intelligent manufacturing professionals that can solve tomorrow's problems already today. While skill requirements are changing rapidly, enterprises, especially SMEs, struggle to find the talent they need. For industry, it is crucial to support the upskilling of their workforce towards new and higher-skilled roles, as competition for talent will become even fiercer in the coming years. For workers, there is a need to take personal responsibility for their learning trajectory and embrace the concept of lifelong learning. How can education and training providers keep pace with this unprecedented level of change? How does a future-proof curriculum look like?

While there are already examples of effective approaches towards adapting engineering training to the needs of Industry 4.0, numerous education and training providers only now begin to consider the necessary development. Reshaping curricula is a considerable challenge, implying complex decision-making processes and various administrative obstacles. Many departments and faculties are still dominated by traditional approaches and subject-related 'silo thinking', while the new industrial age requires fundamentally new mind-sets and visionary leadership.

The current initiative[1] (January 2018 – December 2019) aimed to address the abovementioned challenges by developing the Curriculum Guidelines 4.0, offering education and training providers a systemised overview of the new ways of organising learning experiences of individuals and groups for Industry 4.0. The guidelines aim to provide key stakeholders with an analytical base for developing curricula for the new industrial age. The objective is to offer a source of inspiration, conceptual guidance and good practice examples. The guidelines aim to be applicable for both designing fundamentally new educational offers and advancing existing curricula, depending on the level of required change.

Context and objectives

Advanced manufacturing has a high priority on the political agenda of the European Union, as a key enabler that will lead European society towards a higher industrial competitiveness, sustainable growth and job creation, and improved societal well-being. The AMT domain, including robotics and other forms of automation and material processing devices and machines, is increasing in capability and widening its potential application to low volume, niche and SME-friendly manufacturing opportunities. The ongoing developments have direct implications for the skill requirements, and there is a clear need promote better policies, measures and initiatives at all levels by fostering transparency, increasing awareness and sharing good practices. Specifically, there is a need to reconsider the current approach towards the education and training of AMT

1 "Curriculum Guidelines for Key Enabling Technologies (KETs) and Advanced Manufacturing Technologies (AMT)" initiative (contract nr. EASME/COSME/2017/004) for EASME and DG GROW of the European Commission

professionals and to develop new/advanced models that would be better aligned with the needs of both employers and (future) employees.

The current initiative aimed to contribute to increasing the quality and relevance of existing curricula and to promote better cooperation between industry and education and training organisations in order to align AMT education and training with the needs of the New Industrial Age. It involved data collection and research, design of guidelines, testing and validation, taking into account industry and market needs and best practices, based on contributions from all key stakeholder groups. The initiative focussed on non-tertiary Vocational Education and Training, Higher Education and on-the-job training for AMT.

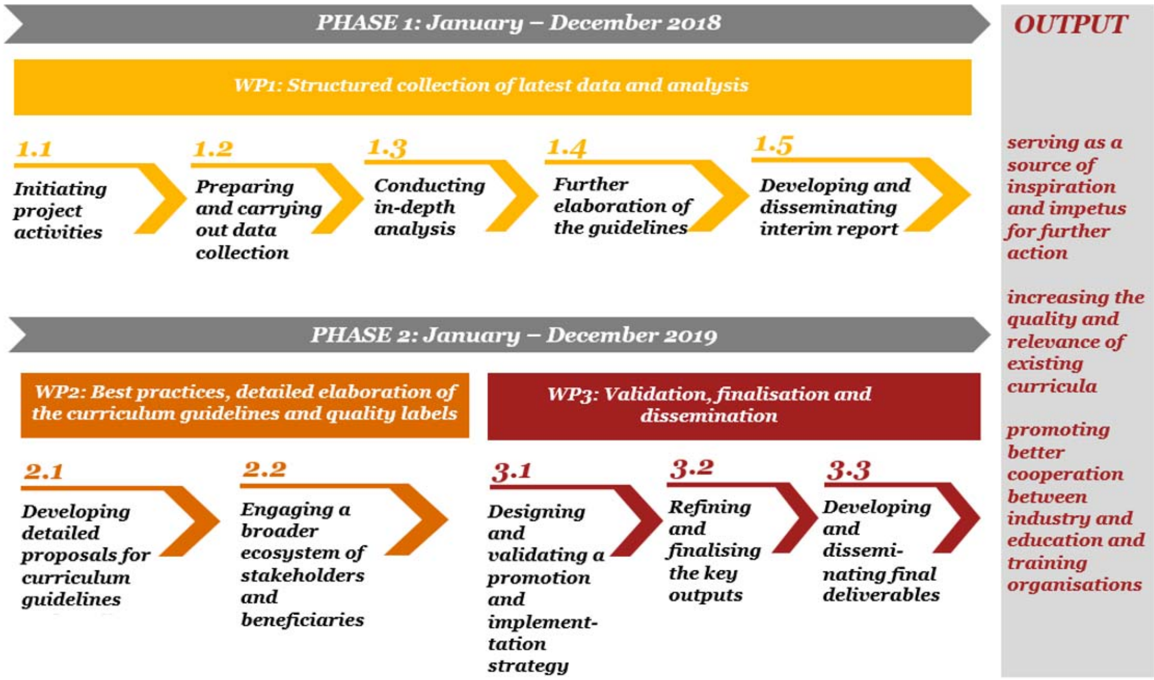

FIGURE 0-1: Design of the Curriculum Guidelines initiative

The outcome of this initiative will play a prominent role in forming the EU policy making regarding the upskilling of the AMT workforce. The initiative aimed to extract suggestions for anticipatory work, and specifically regarding the role of policy makers in reskilling/upskilling the workforce, with a particular attention to the questions of what needs to be done, who can/should do it and how to fund it. The aim was to help likeminded people to find and co-develop solutions, and to provide guidance for implementation.

The target groups of this initiative are all stakeholder groups that have direct influence on the education and training system at different levels, namely teachers/trainers and learners at a micro-level (classroom); managers of educational and training institutions at a meso-level (organisation); and policy makers and supporting structures such as, for example, industry associations, cluster organisations and trade unions at a macro-level (inter-organisational, national and EU levels). The initiative follows a holistic approach and aims to address all key stakeholder groups, while specifying roles and activities for each of these groups. This approach acknowledges that in order to effectively tackle the identified challenges, there is a need for all key stakeholder groups to join forces.

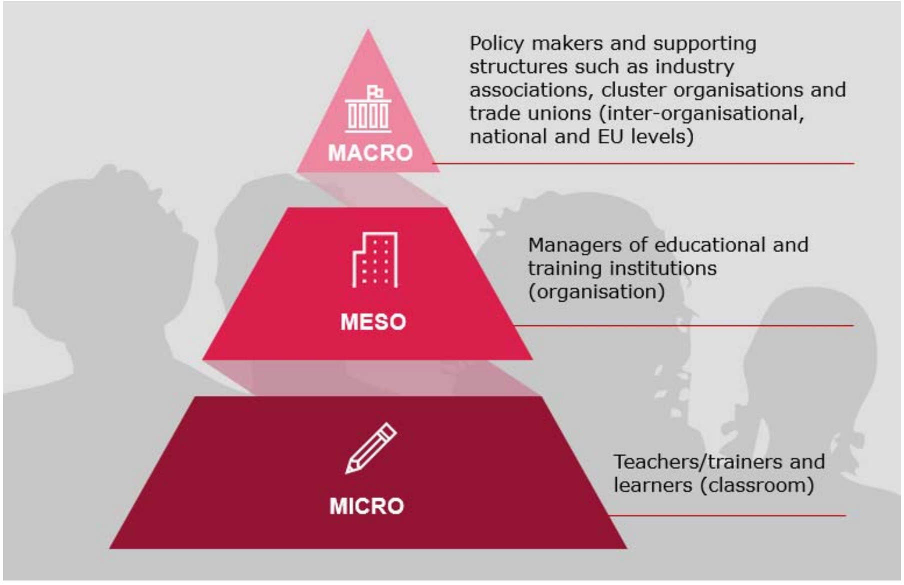

FIGURE 0-2: Target groups of the Curriculum Guidelines initiative

Report structure

The Final Report provides an overview of the key technological (sub-section 2.1.), overall market (sub-section 2.2.) and labour market (sub-section 2.3.) developments. It addresses the key needs in terms of skills (sub-section 3.1.), education (sub-section 3.2.) and training (sub-section 3.3.) in the field of AMT. The report also presents the results of the state-of-play analysis, and it specifically contains a state-of-play analysis with regard to supply and demand of AMT professionals in Europe (sub-section 4.1.), and an analysis of the key players in AMT-related education and training in Europe (sub-section 4.2.). It offers an overview of the relevant strategies, policies and initiatives at the national and EU levels to address the situation regarding the education and training curricula (sub-section 4.3.). Additionally, it highlights the key publications in the field (sub-section 4.4.), and offers sample descriptions of good practice curricula (sub-section 4.5.), and the key barriers for the successful transformation of the AMT-related education and training domain (sub-section 4.6.). Furthermore, the report contains a detailed description of the Curriculum Guidelines 4.0 and addresses the new ways of organising learning experiences of individuals and groups for the manufacturing industry (sub-sections 5.1. – 5.7.). Finally, it presents suggestions for the future promotion and implementation activities (sub-sections 6.1. – 6.5.).

Latest technological trends and market developments for AMT

Industry 4.0 focusses on the end-to-end digitisation of all physical assets and integration into digital ecosystems with value chain partners. The following four key technological developments can be distinguished within 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.

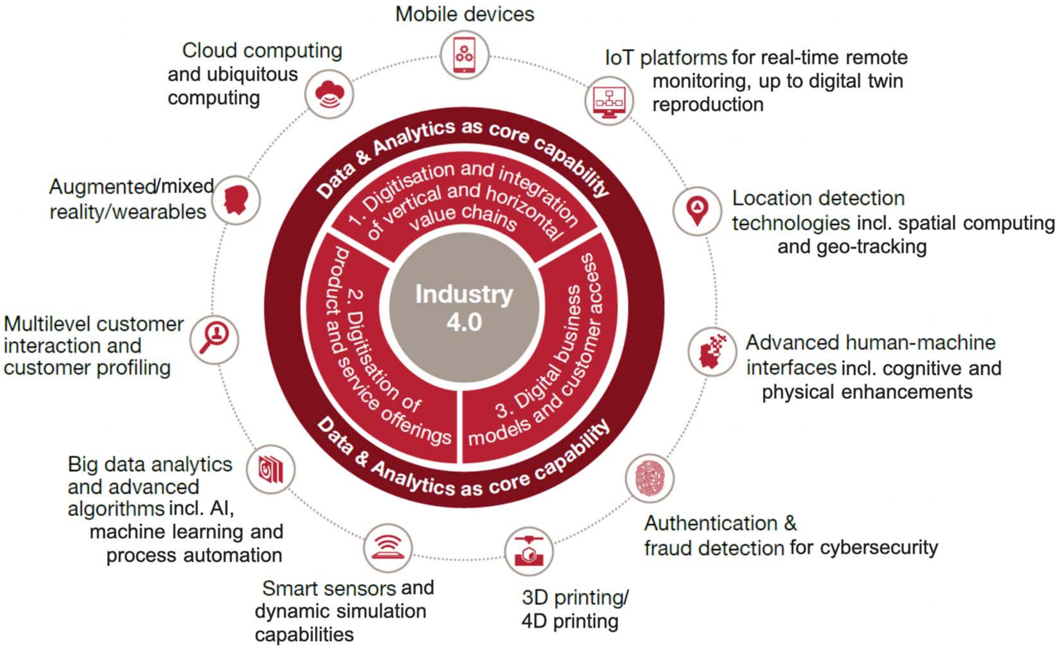

Figure 0-3: Industry 4.0 framework and contributing digital technologies

The AMT market is forecasted to experience a significant growth in the coming years. The Asia Pacific region holds a dominant position on the AMT market and is predicted to witness the highest market growth rate in the coming years compared to other world regions. Various European countries including Germany, France, and the United Kingdom, are also among the leading developers and adopters of smart manufacturing technologies. The North American region also holds a significant share in the overall market share in terms of revenue due to increasing adoption of AMT solutions. When it comes to the digital transformation of manufacturing companies, Europe is reported to be currently lagging behind, compared to Americas and Asia-Pacific.

With regard to the labour market trends, a global decline in total manufacturing and production roles is predicted, driven by labour-substituting technologies such as additive manufacturing, as well as by more resource-efficient sustainable product use, lower demand growth in ageing societies and threats to global supply chains due to geopolitical volatility. The rise of robotics, however, is predicted to lead to labour-complementing productivity enhancement rather than pure job replacement. The manufacturing domain is expected to transform into a highly advanced sector where high-skilled engineers are in strong demand.

Key needs in terms of skills, education and training

The main emphasis still needs to be put on the technical skills forming the core of this profession. Those include, for example, the ability to interact with human-machine interfaces, data management skills, and specialised and interdisciplinary knowledge of technologies and processes. However, rapidly advancing technology requires a general mind-set for continuous improvement and lifelong learning. It is no longer just about what one knows, but increasingly about one’s ability to adapt to continuously changing circumstances and to constantly advance one’s knowledge and skills. Focussing on technical skills only is thus not enough. Other crucial non-technical skills refer, among others, to critical thinking, creativity, communication skills and ability to work in teams.

There is a need for creating hands-on opportunities within education systems, as well as close collaboration of business and educational institutions. Additionally, there is a need for offering learners real-world experience, exposing them to real challenges and advancements of industry and focussing on real-world application of skills. Finally, special attention needs to be paid to the developing and elevating micro-credentialing programs for students and workers and exploring new/alternative forms of education and training.

Supply and demand analysis

The demand for AMT-related skilled labour is significant in several European national economies. The largest calculated demand can be found in Germany, Italy, Poland, France and the United Kingdom. In terms of relative figures, the calculated AMT-related employment constitutes the largest share of the active population in Czech Republic, Slovenia, Slovakia and Hungary. While the analysis suggests that there is mostly enough AMT-related labour supply to satisfy the labour market overall, the differences need to be explored at the level of specific AMT-related occupations. To this end, the report also offers the analysis of the AMT-related labour supply for each AMT-related occupation in each Member State.

Key players in AMT education and training in Europe

Prominent university rankings suggest that Europe currently does not hold a leading position with regard to the quality of the AMT-related higher education offer in the world, although it is still a home base for some of the top universities in this field. Considerable differences can be observed between the EU Member States. The five countries with the highest number of relevant institutions include the United Kingdom, Germany, France, Italy, and Spain, with the highest ranked institutions located in the United Kingdom, Netherlands, Germany, Belgium and Sweden.

On-the-job training varies between different types of organisations and countries, and there is no common system of credentialing workers' skills. Large enterprises have the volume and knowledge to provide sufficient training and education to new workers, and thus often become providers of on-the-job training. The structure allows for tailoring the training to the specific needs of enterprises. On-the-job training also often occurs in interaction and cooperation with leading experts, suppliers and clients. This setting is especially popular among SMEs.

The concept of learning factories have become widespread in recent years in Europe, and have taken many forms of facilities varying in size, scope, function, and complexity. Learning factories have an aim to enhance the learning experience of students and industrial trainees in one or more areas of manufacturing engineering knowledge. Learning factories are also increasingly used as test areas for research. One of the key benefits of learning factories is the possibility of experiential learning, and it can imply both physical and virtual setting.

Relevant initiatives and publications

There are only a few national and subnational policy initiatives explicitly focusing on education and training for AMT. Most of the identified initiatives are larger programmes aimed at enhancing manufacturing and national competitiveness, with education and training being one of several pillars. Many of the identified initiatives address educating/training of highly skilled individuals. We have also identified a few initiatives aiming at developing AMT skills in the low-educated workforce, and particularly a few aimed at young, low-educated people who do not yet have any work experience within Advanced Manufacturing. The identified initiatives typically have a multi-year duration. Some of them do not state an explicit closure date. However, most of the initiatives have secured public funding for a given period, usually four-five years. Only a few of the identified initiatives provide the results of formal evaluations. Additionally, a wide range of relevant pan-European initiatives has been launched at the EU level.

A prominent pattern in the analysed literature refers to the need for close cooperation between education and training providers and industry. Involving industry in education and training is considered to be a key element in ensuring that workers are trained in skills demanded by the industry. Related solutions among others include learning factories, apprenticeships, web-based virtual learning, gamification and expert centres.

Key barriers and solutions

Specific barriers for change in education and training systems include the fact that teachers/trainers and administrators are often cautious about change and have limited tolerance for the uncertainty that any major innovation causes; there is a lack of trust to teachers/trainers when it comes to initiating innovation; innovation in education and training is not promoted/supported in a top-down way; significant efforts are needed to upscale innovations; and learners are often left out of the equation.

The solutions to address the abovementioned barriers can be grouped into the following key directions for action: moving from a teacher-/trainer-centered approach towards a student-centered approach in learning; developing educational leadership to create visions, strategies and incentives, and promoting innovation in teaching/training; investing in the professional development of teachers/trainers; exploring alternative forms of accessing equipment and infrastructure, and convincing companies about the benefits of employee training.

Developing curricula for the VUCA world

Curriculum development must reflect the true nature of the world. The world, in turn, is changing with an unprecedented speed, increasing our inability to grasp the change. For several years, the term "VUCA" is gaining popularity as a notion that covers the various dimensions of this ‘uncontrollable’ environment, namely Volatility, Uncertainty, Complexity and Ambiguity. Providing relevant education and training in the VUCA world requires a mind-set shift, with an aim to convert uncontrollable chaos into manageable complexity. The latter can be achieved with the help of the following four elements: Vision, Understanding, Commitment, and Agility. The Curriculum Guidelines 4.0 aim to offer key guiding principles that could assist education and training providers with a shift from the uncontrollable VUCA towards the more manageable VUCA, when developing and implementing their curricula.

Curriculum Guidelines Framework

The framework was specifically designed, fine-tuned and validated by means of individual expert consultations and multiple expert workshops. The objective of the framework is to provide a holistic overview of all key elements relevant for curriculum design and implementation from broader perspective, namely viewing the curriculum as the overall learning experience of individuals (and groups) throughout their professional lives. It serves as an analytical structure for plotting the identified conceptual principles and good practice examples. It consists of eight distinctive but interconnected elements: (1) Strategy; (2) Collaboration; (3) Content; (4) Learning environment; (5) Delivery mechanisms; (6) Assessment; (7) Recognition; and (8) Quality. The analysis specifically focussed on the first four elements of the framework, as those were suggested by the stakeholders to require key attention when it comes to reshaping the current curricula.

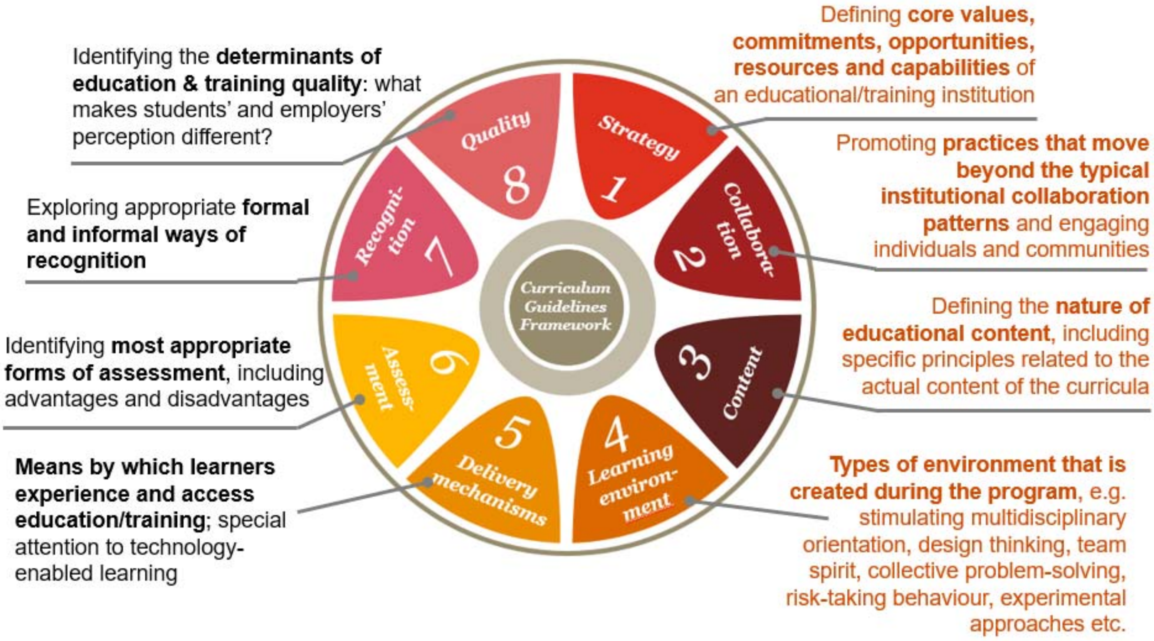

FIGURE 0-4: Curriculum Guidelines framework

Strategy

Having a clear strategy for curriculum development allows for obtaining a better picture of what the desired future should look like, and for shifting from a reactive towards a proactive approach. The conceptual principles that were derived specifically for the Strategy element of the framework include:

- **Preparing students for life-long learning**, i.e. making sure the educational offer develops the ability and readiness of students to engage in continuous learning throughout their professional lives;
- **Offering 'big picture education'**, keeping in mind the bigger picture of how the educational offer fits into the overall learning trajectory and labour market;
- Considering not only **market/company needs** (employability), but also **societal needs** (sustainability, ethics) and **learner's needs/individual characteristics** (i.e. respecting diversity of learners' contexts and capacities);
- **Shifting from knowledge towards competencies** that learners should acquire for their personal development and for employment and inclusion in a knowledge society; adding a dimension of **Mindsets**, e.g. Growth, Innovation, Ethics and Safety;
- Ensuring freedom of curriculum goals and learning outcomes from conventional qualification frameworks to offer **relevant personalised and personal learning;**

- Viewing **learners as change agents** and actively engaging them in curriculum development and implementation.

Collaboration

Moving towards a paradigm of lifelong learning, educational institutions also need to evolve and occupy new roles in the ecosystem. It also implies the evolution of existing and the emergence of new collaboration patterns. These changes may occur within institutions and between institutions. Different types of collaboration are needed, to ensure a multitude of experiential opportunities, including collaboration with companies (i.e. manufacturers, technology providers, start-ups), other educational institutions (via joint platforms, thematic networks etc.), peers (peer-to-peer learning), supporting structures (e.g. industry associations, cluster organisations and similar), governments, community and the evolving breed of human counterparts, machines. The conceptual principles that were derived specifically for the Collaboration element of the framework include:

- Further **increasing university-industry collaboration** in terms of both volume and diversity of collaboration forms (e.g. internships/apprenticeships, mentoring, project banks, think tank competitions, summer schools etc.);

- Acknowledging the role of industry partners as educational, research and employment partners, and ensuring their **engagement in the full student's learning experience**, including strategy development;

- Creating more opportunities for **exchanging experiences with other educational institutions** (e.g. via joint platforms, thematic networks etc.);

- **Facilitating peer-to-peer learning**, to enable learners to learn with and from each other;

- Creating effective **learning ecosystems** that engage all key stakeholder groups, including education and training providers, industry, policy makers, supporting structures and broader community;

- **Shifting from human-machine interaction towards human-machine collaboration** as an evolving collaboration form.

Content

The Content dimension here refers to the nature of educational content and includes specific conceptual principles related to the actual content of the curricula, i.e. syllabus. The derived conceptual principles include:

- **Upgrading the technical side of the curriculum** to accommodate the learning of next-generation robotics, additive manufacturing, smart materials, Artificial Intelligence and machine learning, Internet of Things, predictive analytics, augmented and virtual reality technologies etc.;

- Incorporating **non-technical disciplines** into the curriculum (e.g. communication, project management, arts, marketing etc.), in order to develop cross-cutting competencies and a mind-set beyond technical expertise;

- Paying special attention to the questions of **ethics, social inclusion, diversity and sustainability** (e.g. incorporating the Sustainable Development Goals (SDGs) into the curricula);

- Offering a **holistic view of a product and system life cycles**, in which students learn to alternate between the abstract and the precisely detailed, to deconstruct big problems and accept failure and model real-life situations by simplifying assumptions;

- Teaching students and workers **how to acquire knowledge from the ever increasing 'ocean' of data**, and how to find out what to make of it when it has been found;

- Teaching students and workers to be mindful of their **safety and ergonomics at work**, and specifically about the necessity of maintaining good physical and mental health, and the possible consequences of risk exposure (including what can be done about it).

Learning environment

The learning environment, both physical and virtual, can be organised in a myriad of different ways, and it needs to stem from the strategy and the specific objectives/desired learning outcomes. Specific conceptual principles for the new industrial age include:

- Applying **problem-based learning**, i.e. stimulating learners to work on challenging real-life problems for which there are no established answers; encouraging learners to contextualise their theoretical learning in relation to how it would be useful in the world around them;

- Instead of focus on standardised thinking, correct answers and objectivity of judgment, creating a learning environment that would **stimulate creativity, forming of own opinion and divergent interpretations**;

- Creating a **culture that accepts potential failures** and developing the ability in students to turn those failures into valuable learning experiences;

- Creating learning environments that can offer **experiences relevant to real-world working conditions** (i.e. in a physical and/or virtual form, maximally resembling a factory setting, featuring modern and state-of-the-art equipment);

- Encouraging **collaborative learning** by offering suitable physical spaces and virtual platforms for diverse forms of collaboration, including collaboration with peers, industrial partners, community etc.;

- **Stimulating technology-enabled learning**, encouraging the use of technology and software applications for learning, including Massive Open Online Courses (MOOCs), m-learning, gamification, Augmented and Virtual Reality, Artificial Intelligence etc.

Remaining elements of the framework

The remaining elements of the framework include Delivery mechanisms, Assessment, Recognition and Quality. Delivery mechanisms refer to the means by which learners experience and access education/training, and include in-person delivery where teachers/trainers and learners interact face-to-face (e.g. lectures, seminars, workshops); electronic delivery (synchronous and asynchronous), and blended delivery (education that combines multiple types of delivery). Here, the analysis aimed at addressing the role of technology-enabled learning, including traditional e-learning, MOOCS, SPOCs, m-learning, gaming, virtual and augmented reality, AI solutions etc.

The analysis also implied examining the relevant forms of assessment and recognition. The latter refers to the process, usually carried out by an accredited institution, of issuing a certificate, diploma or title which has formal value; and the process of formally acknowledging and accepting credentials, such as a badge, a certificate, a diploma or title issued by a third-party institution. Within this dimension, the analysis aimed at exploring appropriate formal and informal ways of recognition. Finally, the analysis also addressed the determinants of education and training quality.

Future promotion and implementation activities

In order to achieve impact from the developed Curriculum Guidelines, there is a need to ensure their massive dissemination and the facilitation of their adoption by all key stakeholder groups. For that, a dedicated roadmap was developed.

At the micro-level, the key activities for teachers refer to raising awareness about curriculum guidelines principles among learners; proactively looking for good practice examples and exchanging experiences with professionals who already practice these principles; and proactively initiating discussions with institutional leaders to consider the opportunities to integrate specific principles into the curriculum. Learners, in turn, need to proactively integrate curriculum guidelines principles into their own learning trajectories.

At the meso-level corresponding to organisations and their leaders, there is a need for raising awareness about curriculum guidelines principles within the organisation; embedding it into the strategy at the institutional level; and developing operational approach for the implementation of these principles in practice, taking into account specific learners' needs and context.

Finally, at the macro-level that corresponds to interorganisational, national and European dimensions, the key directions for action include developing multi-stakeholder initiatives aiming to ensure massive implementation of curriculum guidelines principles in practice, for example, initiatives aiming to create massive awareness about a specific curriculum guidelines principle; to produce specific tools and materials that would enable its effective implementation; to offer virtual and physical collaboration spaces for exchanging experiences, lessons learned and good practices etc.

While actions at micro- and meso-levels often can be implemented individually, at the level of specific teachers and learners and organisations, they would significantly benefit from exchanging experiences, good practices and lessons learned with each other. This exchange could be effectively enhanced by introducing collaboration platforms (both physical and virtual), i.e. dedicated spaces where peer-to-peer collaboration and exchange could take place. For learners and teachers at the micro-level, such platforms could be developed by organisational leaders at the meso-level. At the same time, for similar exchanges between organisations (companies and/or education and training providers), such platforms would need to be developed at the macro-level.

Whenever possible, existing platforms should be mobilised for the abovementioned purposes (e.g. Learning/teaching factories, Learning Labs, Living Labs, Innovation Hubs, Makerspaces etc.). Such platforms facilitate expertise and cost sharing, and provide access to a large number of learners to the state-of-the-art equipment, software and technology. The actions to be taken at the macro-level can often only be implemented collectively, i.e. by joining forces, and often of multiple stakeholder groups simultaneously.

In order to ensure continuity, progress and co-creation efforts, there is also a need for developing a dedicated thematic network/roundtable. The latter would enable a continuous dialogue and networking to help manufacturing-related education and training providers to faster adapt their curricula to the needs of the new age. The two key objectives of the network would include:

- Promoting the wide adoption of the Curriculum Guidelines across the EU;
- Connecting education and training providers active in manufacturing-related domain and facilitating the exchange of experiences, lessons learned and good practice examples, developed solutions, as well as practical tools that would equip teachers and trainers.

Such network will need to develop synergies with other relevant initiatives, including the Blueprint for Sectoral Cooperation on Skills.

Furthermore, in order to continuously monitor the evolving skill needs of the manufacturing domain, and to analyse the corresponding implications for education and training, a dedicated Skills Observatory could be created at the EU level. The Observatory could also be used for continuous tracing of the main workforce flows in manufacturing, as well as for monitoring changes in the gap in manufacturing-related skills from both the qualitative and quantitative perspectives.

Finally, special attention needs to be paid to supporting the professional development of educators and trainers in an effective and systemised way. In that regard, the Irish National Professional Development Framework can be referenced as a good practice example that could be promoted at the EU level.

1. INTRODUCTION

This document represents the Final Report for the "Curriculum Guidelines for Key Enabling Technologies (KETs) and Advanced Manufacturing Technologies (AMT)" initiative (contract nr. EASME/COSME/2017/004, hereafter "Curriculum Guidelines initiative"), prepared by PwC EU Services (hereafter "PwC") for the Executive Agency for Small and Medium-sized Enterprises (hereafter "EASME") and the Directorate General for Internal Market, Industry, Entrepreneurship and SMEs (hereafter "DG GROW") of the European Commission (hereafter "the Commission").

The Final Report presents the key outcomes of the initiative, and covers the activities carried out in the period from January 2018 until October 2019. The report first provides an overview of the latest technological trends and market developments for AMT[2], and addresses the key needs in terms of skills, education and on-the-job training. Furthermore, it contains a state-of-play analysis with regard to supply and demand of AMT professionals in Europe, the key players in AMT education and training in Europe, as well as the relevant policy initiatives and key publications. The report also provides sample descriptions of good practice curricula, and the key barriers for the successful transformation of the AMT-related education and training system. The report specifically sets priorities for the Curriculum Guidelines 4.0, targeting Europe's education and training providers, and highlighting the key points of attention and good practice examples in the context of education and training for manufacturing in the new age. Finally, the report also offers an overview of the proposed future promotion and implementation activities.

The current chapter presents the context and objectives of the Curriculum Guidelines initiative. It also provides an overview of the key performed activities.

1.1. Context and objectives

Advanced manufacturing has a high priority on the political agenda of the European Union, as a key enabler that will lead European society towards a higher industrial competitiveness, sustainable growth and job creation, and improved societal well-being[3]. Advanced manufacturing technologies, including robotics and other forms of automation and material processing devices and machines, are increasing in capability and widening their potential application to low volume, niche and SME-friendly manufacturing opportunities[4]. The ongoing developments have fundamental implications for the skill requirements, and there is a clear need promote better policies, measures and initiatives at all levels by fostering transparency, increasing awareness and sharing good practices.

2 While the original name of this initiative includes both KETs and AMT, this initiative focusses exclusively on the AMT domain, with a purpose to keep the analysis manageable and practically relevant. Nevertheless, while other KETs are not explicitly addressed, the findings of this initiative may still be relevant also for other KETs.

3 See, for example, http://www.eurekanetwork.org/content/smart-advanced-manufacturing

4 UKCES (2012) "Sector Skills Insights: Advanced Manufacturing", Evidence Report 48

1.1.1. Context and rationale

The manufacturing domain is undergoing a fundamental transformation - known as the fourth industrial revolution or Industry 4.0 - that is driven by the following major developments[5]:

- ***Technology trends***: the advancement of manufacturing is supported by a range of different emerging technologies and systems that enhance organisation, sharing and analysis of data; improved sensing and interacting with the material world; and greater connectivity, data gathering, and control of manufacturing system elements;

- ***Customer demand trends***: evolving customer preferences refer to product variety; personalised products and services; faster response to needs; expectations of added-value services (social media interaction, order status tracking); and societal and economic pressure to increase environmental and resource sustainability;

- ***Industry pressures and drivers***: there is an increasing need for asset and resource efficiency; growing reliance on supply chain and need for robustness and tracking; increasing security risks; shorter product lifecycles; emerging opportunities to offer value-added services throughout product life-cycle; and increasing manufacturing complexity of products, production and data;

- ***Policy and regulatory developments***: an increasing demand for high quality standards, safety and sustainability leads to a focus on creating advanced products that have a smaller environmental impact; a need for high-quality packaging and delivery; and regulatory guidance on, for example, safety and health at work.

A more detailed overview of the relevant technological, market and labour market developments is provided in *Chapter 2* of this report.

As a result of the abovementioned transformation, the number of jobs in manufacturing as a whole in Europe requiring high-level qualifications is projected to rise by 1.6 million (21%) by 2025[6], whereas the growing automation of production processes will lead to a decrease in the number of low- and medium-skilled jobs by over 2.8 million[7]. A similar pattern is expected in the high- and high-medium technology industries within manufacturing, although the shifts are less pronounced at the high-technology end of the scale[8].

5 UNIDO (2017) "Emerging Trends in Global Advanced Manufacturing: Challenges, Opportunities and Policy Responses", Report developed with support of the University of Cambridge and Policy Links
6 European Commission (2014) "EU Skills Panorama: Focus on Advanced Manufacturing"
7 *Ibid*.
8 *Ibid*.

Highlight 1-1: The future of skills in manufacturing[9]

The projected increase in demand for higher-skilled workers includes those with a more **traditional engineering profile** – process engineers, quality control engineers, and chemical, electronic, mechanical or mechatronic engineers. At the same time, due to the centrality of data and information on new technologies, there will also be demand for **newer skill sets** – particularly those of designers, industrial data scientists, 'big data' statisticians/mathematicians and data security analysts – to deal with the increasing data-intensiveness of production processes. There is also a rapidly growing demand for **'symbolic analysts'** capable of processing and interpreting the large amounts of data in designing and producing things.

The most demanded profile is likely to include some **combination of engineering and ICT skills**. Large companies like General Electric increasingly make ICT skills training, including basic coding, mandatory for all new employees 'from top floor to work floor'. The centrality of information processing and computer logic signifies even more far-reaching reforms to educational curricula, including programming skills tuition for primary school students, using products such as Raspberry Pi.

Non-technical skills also become increasingly relevant in manufacturing. Social and communication skills become more important, as many of the game-changing technologies include different, specialised technical domains and require interdisciplinary collaboration between team members and departments, as well as external service providers. Complex environments require clear communication. The capacity to work in teams will be essential, as will adaptability, as individual specialists will be contributing to many different project teams.

Other critical skills include independent decision-making and creativity. Decentralised production processes may require rapid intervention in cases of dysfunction or production 'exceptions'. This is likely to require not only extensive knowledge of technical processes, but also leadership skills and problem-solving capacity, as well as qualities related to temperament ('grace under pressure').

The abovementioned challenges signify **a need to reconsider the current approach towards the education and training[10] of manufacturing professionals** and to develop new/advanced models that would be better aligned with the needs of both employers and (future) employees. Illustrative examples of such new/advanced models are provided in *Annex B* of this report. How can education and training systems keep pace with this unprecedented level of change? How does a future-proof curriculum look like, and how to ensure a massive advancement of existing curricula?

To this end, EASME and DG GROW of the European Commission have launched this initiative for developing **"Curriculum Guidelines for Key Enabling Technologies (KETs) and Advanced Manufacturing Technologies (AMT)"**. It involved data collection and research, design of guidelines, testing and validation, taking into account industry and market needs and best practices, based on contributions from all key stakeholder groups. The initiative focussed on **Vocational Education and Training (VET), Higher Education (HE) and on-the-job training for manufacturing**.

9 Eurofound (2019) "The future of manufacturing in Europe", Publications Office of the European Union, Luxembourg, April 2019

10 At the same time, it is important to highlight that manufacturing professionals can also be supplied by other education and training domains, not explicitly related to manufacturing. However, in the context of the current initiative, we will examine explicitly AMT-oriented educational offer in Europe, in order to keep the analysis focussed and manageable.

Two distinctive but closely interrelated directions for action were explored:

Teaching[11] new skills:

- New technical skills, emotional/social intelligence, multidisciplinary mind-set, learning-to-learn skills, systems thinking, STEAM (STEM with Arts) etc.;

Teaching skills in a new way:

- Student-centred approach[12];
- Problem-based learning and experience-based learning (real-life cases, apprenticeships, engaging employers in curriculum development etc.);
- Technology-enhanced learning (MOOCs, augmented/virtual reality, AI etc.);
- Learning ecosystem: connecting learners to employers and other key stakeholders through project work, industrial placements, matchmaking events etc.
- Upskilling teachers and equipping them with the right tools etc.

The outcome of this initiative aims to offer a contribution for the future EU policy making regarding upskilling of the AMT workforce.

The current initiative falls under the umbrella of the "**Skills for Industry Strategy**" theme, with the latter covering multiple topics related to upskilling and reskilling of the European workforce. Other related initiatives of the Commission include "Online Training: Promoting Opportunities for the Workforce in Europe"[13], "Skills for Smart Industrial Specialisation and Digital Transformation"[14], and "Scaling-up Best Practices and re-Focusing Incentives"[15]. It is also closely linked to the activities of the Blueprint for Sectoral Cooperation on Skills[16].

The Blueprint in its essence provides a framework for strategic cooperation between key stakeholders such as enterprises, trade unions, research and training institutions and public authorities in a given economic sector. It implies industry-led partnerships that develop sectoral skills strategies and concrete actions, such as new or updated vocational education and training. The overall goal is to help foster new opportunities for investment, innovation, growth and jobs[17].

The pilot implementations of the Blueprint started in January 2018 in the following sectors: automotive, maritime technology, textile, clothing, leather and footwear,

11 A distinction needs to be made between teaching and learning. Teaching is the act of communicating ideas, emotions, and/or skills to learners, and is performed by teachers. Learning, in turn, is the acquisition of new information or the modification of existing knowledge, preferences, expertise, and other aspects of behavior of learners (based on http://www.differencebetween.net/language/words-language/difference-between-teaching-and-learning/), and is performed by learners. Learning and teaching are the foundation of education and training. These two activities are closely connected, and effective teaching is a vital component of education. However, learning often occurs without teachers in situations where learners learn by experience or by their own efforts (based on https://eduflow.wordpress.com/2013/11/06/learning-versus-teaching/)

12 For more information, please refer to section 3.2.4.

13 https://publications.europa.eu/en/publication-detail/-/publication/812aeaf7-dccd-11e8-afb3-01aa75ed71a1

14 https://skills4industry.eu/

15 *Ibid.*

16 http://ec.europa.eu/growth/industry/policy/skills_en

17 https://ec.europa.eu/social/main.jsp?catId=738&langId=en&pubId=8164&type=2&furtherPubs=yes

space and tourism. The second wave of implementation started in January 2019 and included construction, steel, additive manufacturing, and maritime shipping. The third wave is expected to be launched in January 2020, and the selected sectors include microelectronics, batteries for electro-mobility, defence technologies, energy value-chain digitalisation, energy-intensive industries, and bio-economy (new technologies in agriculture)[18]. The next wave has already been announced and it will cover software services, cybersecurity and blockchain.

1.1.2. General objective

The overall objective of this service contract was **to contribute to increasing the quality and relevance of existing curricula and to promote better cooperation between industry and education and training organisations**. The initiative specifically aimed at the development, promotion and implementation of pan-European curriculum guidelines (hereafter "Curriculum Guidelines 4.0"), highlighting the new ways of organising learning experiences of individuals and groups for the manufacturing industry. The guidelines aim to provide key stakeholders with an analytical base for developing curricula for the new industrial age. The objective is to offer a source of inspiration, conceptual guidance and good practice examples. The guidelines aim to be applicable for both designing fundamentally new educational offers and advancing existing curricula, depending on the level of required change. The initiative aims to extract suggestions for **anticipatory work**, and specifically with regard to the role of policy makers in reskilling/upskilling the workforce, with a particular attention to the questions of what needs to be done, who can/should do it and how to fund it. The anticipatory work here implies preparing for the future by developing different scenarios, sharing them with stakeholders and reaching consensus on what has to be done. Policy makers need to develop a vision that is supported by all key stakeholder groups.

The aim is to help likeminded people to find/co-develop solutions and to provide guidance for implementation. There is also a need to develop a mechanism for updating the guidelines on a regular basis, as well as for recommendations on scaling up existing best practice efforts.

The **target groups** of this initiative are all stakeholder groups that have direct influence on the education and training system at different levels (see Figure 1-1), namely teachers/trainers and learners at a *micro-level* (classroom); managers of educational and training institutions at a *meso-level* (organisation); and policy makers and supporting structures such as, for example, industry associations, cluster organisations and trade unions at a *macro-level* (inter-organisational, national and EU levels). The term "target group" here refers to the stakeholders that this initiative aims to reach as *change agents* for the current education and training system. The initiative follows a holistic approach and aims to address all key stakeholder groups, while specifying roles and activities for each of these groups. This approach acknowledges that in order to effectively tackle the identified challenges, there is a need for all key stakeholder groups to join forces.

18 http://ec.europa.eu/growth/industry/policy/skills_en

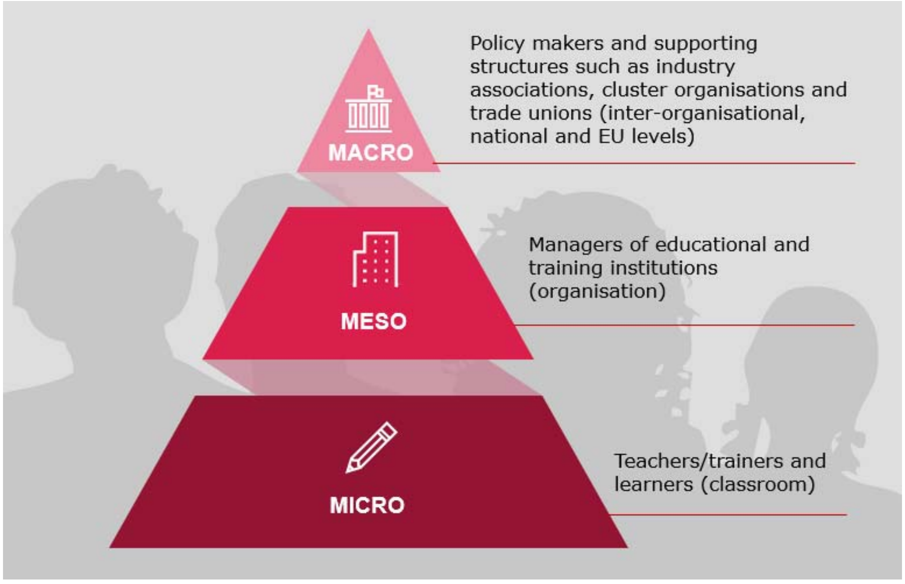

FIGURE 1-1: Target groups of the Curriculum Guidelines initiative

The outcomes of this initiative aim to contribute to the efforts of the European Commission and Member States to facilitate the successful implementation of the "New Skills Agenda"[19] for Europe and of the European industrial policy[20].

Stakeholder engagement was incorporated into all key stages of this initiative, through expert workshops, online surveys, in-depth interviews and individual expert consultations, as well as a dedicated LinkedIn discussion platform.

1.1.3. Specific objectives

The key specific activities carried out within this initiative include the following:

- Reviewing the relevant information, to constitute an initial basis of evidence concerning skills and curricula for AMT, and to better prepare the collection of new and added-value material;
- Researching, collecting through desk research and other means, of the latest information and data with a view to providing a comprehensive picture of the state-of-the-art in the EU concerning: (1) the most important needs of enterprises and – specifically – SMEs related to AMT and - based on these needs - (2) the most relevant educational and training curricula and their delivery (including learning factory, digital learning and blended learning etc.);
- Performing an in-depth analysis of the gathered data and getting feedback on the findings from the key stakeholders and policy makers regarding the relevance, quality and effectiveness of the existing curricula;
- Drafting and delivering an interim report "Curricula for KETs and AMT skills: State-of-play in Europe" to present detailed results of the analysis;
- Identifying and documenting best practices related to AMT curricula in higher education and vocational education and training organisations in Europe;

19 https://ec.europa.eu/social/main.jsp?catId=1223
20 https://ec.europa.eu/growth/industry/policy_en

- Designing pan-European guidelines for new curriculum development for AMT skills, based on the results of the analysis, best practices and in-depth consultation with stakeholders;

- Engaging a broader ecosystem of stakeholders and potential end-users in testing and validating the proposed curriculum guidelines;

- Drafting and delivering the final report, presenting the state-of-play, best practices, curriculum guidelines, formulated recommendations, and a roadmap for promotion and implementation of Curriculum Guidelines 4.0;

- Producing a high-quality brochure and widely disseminating the results.

A final conference will be organised in Brussels in November 2019. At this occasion, we will prepare a press release and disseminate the brochure. The event will target policy makers and key stakeholders, especially industry, SMEs, and education and training organisations from all EU Member States.

1.1.4. Expected results

The results of this initiative aim to inform policy-makers, educators, business and supporting structures on better curricula, policies, measures, partnerships, and initiatives on AMT skills, aimed at enterprises and SMEs, as well as contribute to advancing Europe's talent pool and the competitiveness of the European industry.

The **main results** aim to:

- Promote better policies, measures and initiatives at all levels on AMT skills for SMEs by fostering transparency and increasing awareness;

- Facilitate the uptake by SMEs of these technologies, by strengthening the human capital and skills dimensions and providing efficient tools;

- Create a feedback loop between policy makers, business and social leaders and SMEs;

- Improve the relevance and quality of curricula for AMT skills development; *and*

- Contribute to the further development and improvement of European and national initiatives on AMT skills.

1.1.5. Project design

The tasks of this initiative were grouped into three Work Packages (WPs) corresponding to the two main phases of 12 months each (see Figure 1-2).

The **first phase** (January 2018 – December 2018) was dedicated to research, collection and analysis of latest information and data, based on desk research, expert workshops and interviews with key stakeholders. The Interim Report[21], presenting the results of the analysis and the state-of-play in the EU on education and training for AMT, signified the end of this phase. The Interim Report was later integrated into the final report.

21 https://publications.europa.eu/en/publication-detail/-/publication/4dcaeee3-29c2-11e9-8d04-01aa75ed71a1/language-en/format-PDF/source-87225354

The results of the first online survey of this initiative (conducted in the end of 2018) indicated that **the four elements of the AMT-related education and training system that require the most substantial change include**:

- **Strategy**: What are promising strategies and conceptual principles for developing a 21st Century curriculum for Advanced Manufacturing? (including strategies for assessing learner's needs, developing curriculum goals and intended learning outcomes);
- **Collaboration**: What are promising collaboration practices for facilitating the exchange of knowledge and resources with a view to improve the educational offer for Advanced Manufacturing? (e.g. engaging companies throughout the whole curriculum development and implementation trajectory, empowering learners to collaborate with each other and with the institution and community etc.);
- **Learning environment**: What types of environment lead to the most effective learning for Advanced Manufacturing? (e.g. stimulating multidisciplinary orientation, design thinking, team spirit, collective problem-solving, risk-taking behaviour, experimental approaches etc.); *and*
- **Content**: What should be the nature of the educational content, including specific principles related to the actual content of the curricula?

The **second phase** (January 2019 – December 2019) of this initiative was devoted to collecting inputs specifically for these four elements. This phase concentrated on further documenting best practices, engaging a broader ecosystem of stakeholders, designing pan-European curriculum guidelines, and formulating recommendations. The Final Report presents the key outcomes of the analysis from both phases.

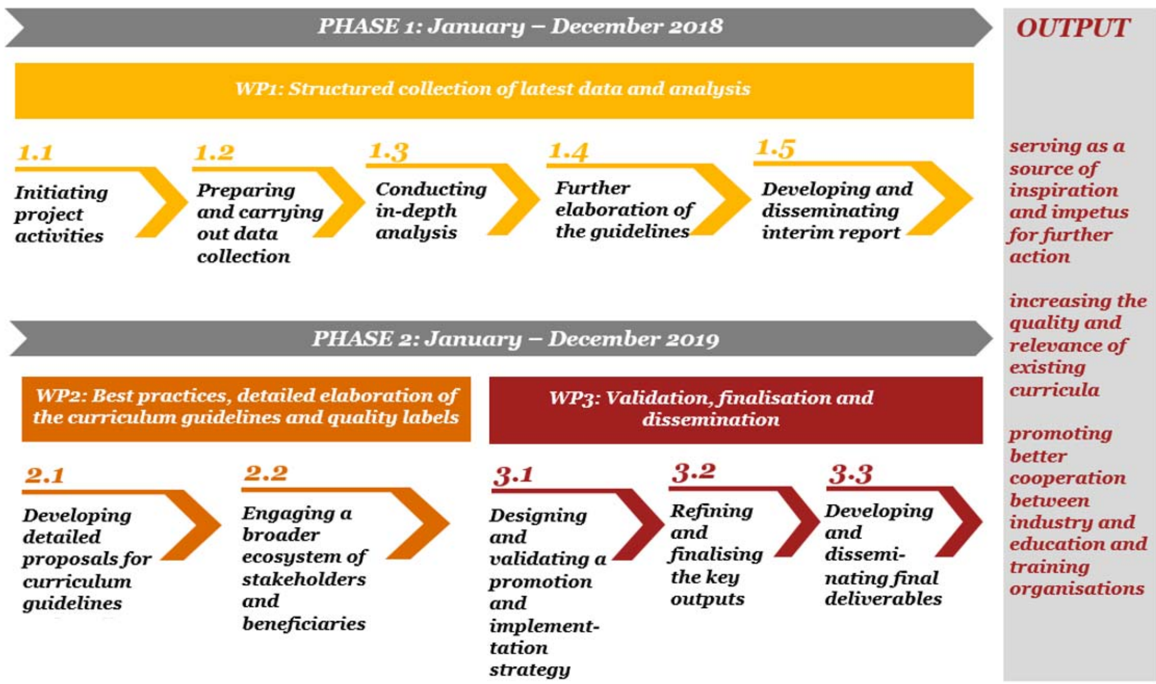

FIGURE 1-2: Design of the Curriculum Guidelines initiative

1.2. Report structure

The Final Report is structured as follows. **Chapter 2** provides an overview of the key technological, overall market and labour market developments. **Chapter 3** addresses the key needs in terms of skills, education and training in the field of AMT. **Chapter 4** presents the results of the state-of-play analysis, and specifically contains a state-of-play analysis with regard to supply and demand of AMT professionals in Europe, and an analysis of the key players in AMT-related education and training in Europe. It also presents an overview of the relevant strategies, policies and initiatives at national and EU levels to address the situation regarding the education and training curricula. Additionally, it highlights the key publications in this field, and offers sample descriptions of good practice curricula, and the key barriers for the successful transformation of the AMT-related education and training domain. **Chapter 5** offers a detailed description of the Curriculum Guidelines 4.0 and addresses the new ways of organising learning experiences of individuals and groups for the manufacturing industry. **Chapter 6** presents the overall policy recommendations, including a roadmap for promotion and implementation of the guidelines.

Annex A contains the key outcomes of the six expert workshops and the final conference organised in the context of this initiative. **Annex B** offers illustrative examples of new/alternative approaches towards education and training. **Annex C** provides a detailed overview of the key technological developments within AMT and contains the resulting implications for curriculum requirements. **Annex D** contains good practice curricula descriptions. **Annex E** analyses AMT-related labour supply for each AMT-related occupation in each Member State. Finally, **Annex F** offers an overview of publications and other online sources that were used for the analysis.

2. LATEST TECHNOLOGICAL TRENDS AND MARKET DEVELOPMENTS FOR AMT

This chapter presents an overview of the latest technological, market and specifically labour market trends in the field of AMT, with an objective to set the scene for the analysis in the following chapters. The current chapter does *not* aim to provide a comprehensive and detailed trends overview. Instead, it aims to further sketch the context for the key topic of the analysis of the current initiative, namely curriculum guidelines and accompanying policy suggestions.

2.1. Overview of key technological trends

The fourth industrial revolution or Industry 4.0 focusses on the end-to-end digitisation of all physical assets and integration into digital ecosystems with value chain partners[22]. It builds on *a wide range of new technologies* to create value through seamlessly generating, analysing and communicating data.

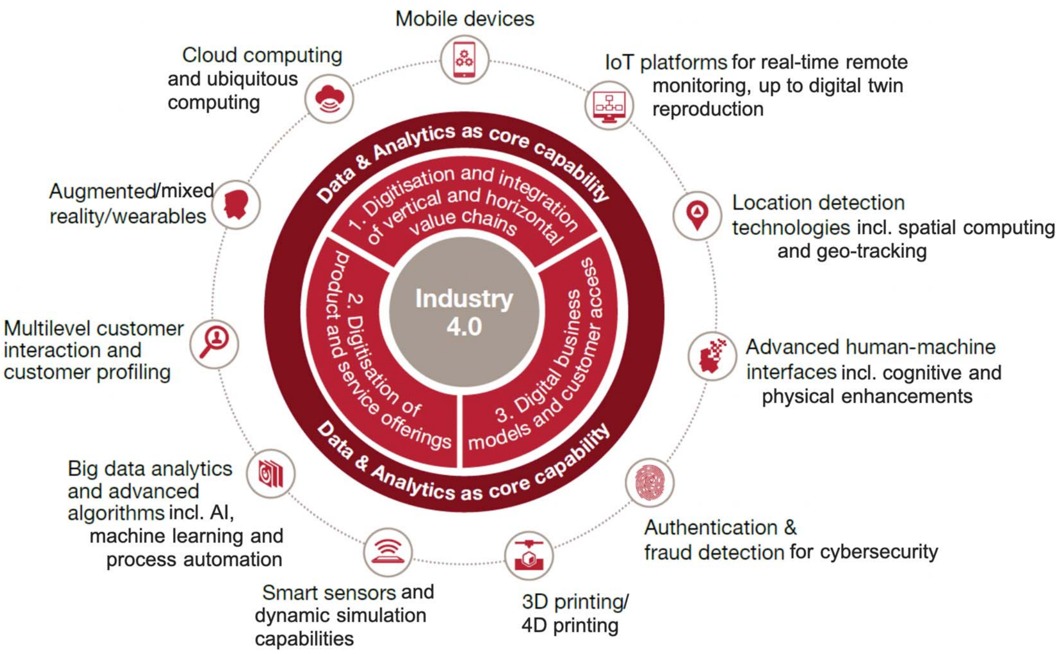

Figure 2-1: Industry 4.0 framework and contributing digital technologies[23]

Specifically, the technological infrastructure of Advanced Manufacturing includes both hardware and software. The hardware segment includes among others robots, 3D printers, Industrial Internet of Things (IIoT) enabling equipment and devices, and augmented and virtual reality devices[24]. Different types of conventional and smart sensors form a significant aspect of the hardware segment. When it comes to the software segment, numerous solutions have already been in use for many years. The solutions include among others manufacturing execution systems, product lifecycle management, and enterprise resource planning. However, the modernisation of these

22 PwC (2016) "Industry 4.0: Building the digital enterprise"
23 *Ibid*.
24 Grand View Research (2017) "Smart Manufacturing Market Analysis By Component, By Technology, By End-use (Automotive, Aerospace, Chemicals, Healthcare, Electronics, Agriculture, Oil & Gas), By Region, And Segment Forecasts, 2018 - 2025"

systems and growth of analytics and AI-enabled systems are expected to be the driving growth factors for AMT for years to come[25]. Figure 2-1 provides an overview of some key technologies contributing to Industry 4.0.

The following four key technological developments can be distinguished within Industry 4.0[26]:

(1) **Digitisation and integration of vertical and horizontal value chains**: Industry 4.0 implies vertical digitisation and integration of processes across the entire organisation, from product development and purchasing, through manufacturing, logistics and service. All data about operations processes, process efficiency and quality management, as well as operations planning become available real-time, supported by augmented reality and optimised in an integrated network. Horizontal integration goes beyond the internal operations from suppliers to customers and all key value chain partners. It includes technologies from track and trace devices to real-time integrated planning with execution.

(2) **Digitisation of product and service offerings:** it includes the expansion of existing products, e.g. by adding smart sensors or communication devices that can be used with data analytics tools, as well as the creation of new digitised products which focus on completely integrated solutions. By integrating new methods of data collection and analysis, companies become able to generate data on product use and refine products to meet the increasing needs of end-customers.

(3) **Digitisation of business processes and way of working:** part of the industry pressure to move towards Industry 4.0 also comes from the fact that new technologies are changing the way products are designed, manufactured and subsequently distributed to end-users. From customer service to factory floor, new technologies like robotic process automation, smart assistants, collaborative robots (cobots) and exoskeletons are not so much replacing humans as enhancing what a human can do in a limited amount of time. These productivity benefits should not be underestimated.

(4) **Digitisation of business models and customer access:** Industry 4.0 also implies expanding company offering by providing disruptive digital solutions such as complete, data-driven services and integrated platform solutions. Disruptive digital business models typically focus on optimising customer interaction and access and generating additional revenue. Digital products and services often aim to serve customers with complete solutions in a distinct digital ecosystem.

In order to get a more comprehensive overview of the technological trends in AMT, we suggest looking at the key processes within manufacturing that can be enhanced with technology (see Figure 2-2). An extensive glossary of Advanced Manufacturing technologies and techniques can be found on the Manufacturing.gov portal maintained by the National Institute of Standards and Technology (NIST)[27].

25 PwC (2016) "Industry 4.0: Building the digital enterprise"
26 *Ibid*.
27 Advanced Manufacturing National Program Office. (n.d.) "Glossary of Advanced Manufacturing Terms". Retrieved October 13, 2018

A detailed overview of the key technological developments within each of the identified areas of Figure 2-2 is presented in *Annex* C. This Annex also contains the resulting implications for curriculum requirements.

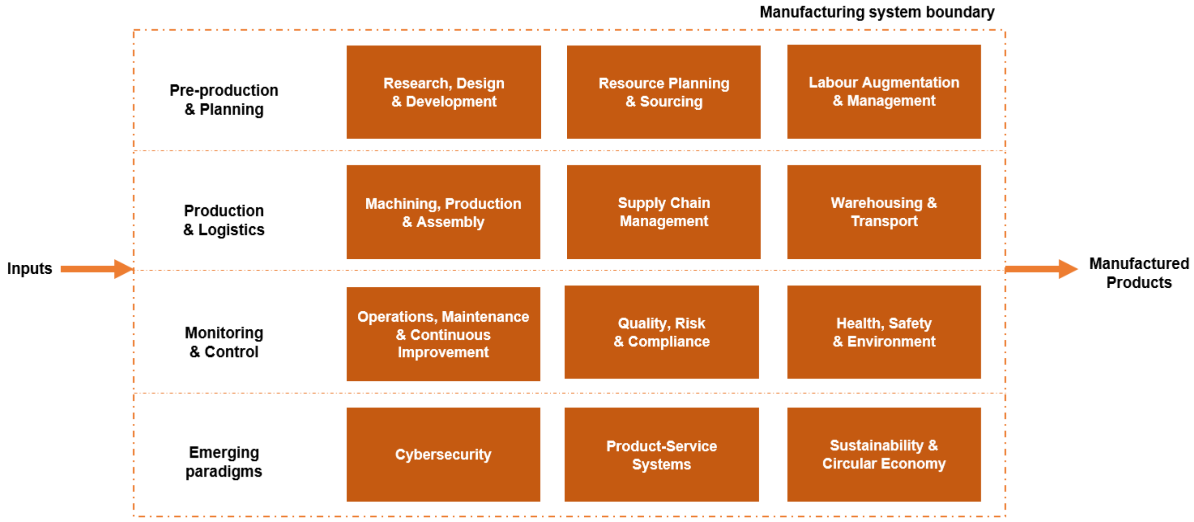

Figure 2-2: Areas for technological enhancement in the context of Advanced Manufacturing

2.2. Overview of key market developments

According to the report by Mordor Intelligence[28], the Global Smart Manufacturing market was estimated at 211.97 billion USD (185.54 billion EUR[29]) in 2017, and it is expected to reach a value of 595.29 billion USD (521.07 billion EUR[30]) by 2023 at a Compound Annual Growth Rate (CAGR) of 18.78%, during the forecast period of 2018-2023[31]. The report by MarketsandMarkets[32] provides somewhat less ambitious figures, and values the smart manufacturing market at 153.25 billion USD (134.14 billion EUR[33]) in 2017, while forecasting that it will reach 299.19 billion USD (261.89 billion EUR[34]) by 2023, at a CAGR of 11.9% from 2018 to 2023[35]. At the same time, Grand View Research[36] estimated the global smart manufacturing market size to reach

28 Mordor Intelligence (2018) "Smart Manufacturing Industry Size - Segmented by Technology (PLC, SCADA, ERP, DCS, HMI, PLM, MES), Components (Control Device, Robotics, Communication Segment, Sensor), End-user (Automotive, Semi-conductor, Oil & Gas, Chemical & Petrochemical, Pharmaceutical, Aerospace & Defense, Food & Beverage, and Mining), and Region - Growth, Trends, and Forecast (2018 - 2023)", published in March 2018

29 Based on the google currency converter of 27 October 2018

30 *Ibid*.

31 The scope of the report is limited to products offered by major players for smart manufacturing including Programmable Logic Controller, Supervisory Controller and Data Acquisition, Enterprise Resource and Planning, Distributed Control System. The end users considered in the scope of the report include Automotive, Semi-Conductor, Oil & Gas, Chemical & Petrochemical, Pharmaceutical, Aerospace & Defense, Food & Beverage, and Mining.

32 MarketsandMarkets (2018) "Smart Manufacturing Market by Enabling Technology (Condition Monitoring, Artificial Intelligence, IIoT, Digital Twin, Industrial 3D Printing), Information Technology (WMS, MES, PAM, HMI), Industry, and Region - Global Forecast to 2023", published in October 2018

33 Based on the google currency converter of 27 October 2018

34 *Ibid*.

35 The report covers the following process industries: Oil & Gas, Food & Beverages, Pharmaceuticals, Chemicals, Energy & Power, Metals & Mining, Pulp & Paper and others. The report covers the following discrete industries: Automotive, Aerospace & Defense, Semiconductor & Electronics, Medical Devices, Machine Manufacturing and others.

36 Grand View Research (2017) "Smart Manufacturing Market Analysis By Component, By Technology, By End-use (Automotive, Aerospace, Chemicals, Healthcare, Electronics, Agriculture, Oil & Gas), By Region, And Segment Forecasts, 2014 - 2025", published in November 2017

395.2 billion USD (345.92 billion EUR[37]) by 2025, which is somewhere in between the estimates of the abovementioned other two sources. The estimates of Zion Market Research[38] suggest that the global smart manufacturing market was valued at around 152.3 billion USD (133.31 billion EUR[39]) in 2017 and is expected to reach approximately 479.01 billion USD (419.28 billion EUR[40]) in 2023, growing at a CAGR of slightly above 15.4% between 2018 and 2023. The differences in market estimates can be explained by differences in methodologies/sources and scoping of the reports. Nevertheless, the consulted market research sources unanimously agree that the smart manufacturing domain is likely to experience a significant growth in the coming years.

Looking at the drivers behind this growth, industry analysts find that while sizeable market share and diversified product categories may have been sufficient to sidestep obstacles and weather slowdowns in various sectors previously, this strategy may not remain viable[41]. Customer loyalty is no longer a given as there is increased competition for smart connected equipment that provide more transparency. Given the shorter production cycles that manufacturers expect, there is a real fear of investing in soon-obsolescent equipment that cannot be upgraded or enhanced in any way. Furthermore, changes in capital market efficiency are lowering the barriers to entry for new disruptive players.

Hence, manufacturing companies are adapting by investing heavily in connected equipment, sensors, actuators, cloud-based monitoring software and the promise of rich real-time analytics that collected data can potentially yield. 72% of manufacturing companies surveyed by PwC expect to dramatically increase their level of digitisation by 2020, compared to just 33% currently[42]. On average, they are investing about 5% of their revenues towards this goal.

An increasing number of manufacturers are using smart manufacturing technologies for setting standards, for effective trade-off decisions, maintenance, operation, risk assessment, control, logistic, business, and operation. The smart manufacturing market is expected to be boosted by the continuous growth in the adoption of analytical solutions, and the growing focus on cost reduction and business process proficiency. Furthermore, leading players are increasingly offering technologically advanced solutions - designed to overcome modern-day production challenges - also to SMEs[43].

In addition to the technological advancements, fundamental business strategies are also changing among manufacturers who have to allocate finite amounts of capital to stay relevant in an increasingly competitive market[44]. Some companies, for example,

37 Based on the google currency converter of 27 October 2018

38 Zion Market Research (2018) "Smart Manufacturing Market by Technology (PLC, DCS, HMI, MES, PLM, SCADA, and Machine Vision), by Component (Hardware, Software, and Services) for Electronics, Healthcare, Automotive, Oil & Gas, Aerospace & Defense, Food & Agriculture, Industrial Equipment, Chemicals & Materials, and Others by Region (North America, Europe, Asia Pacific, Latin America, and Middle East and Africa): Global Industry Perspective, Comprehensive Analysis, and Forecast 2017-2023", published on 16 May 2018

39 Based on the google currency converter of 27 October 2018

40 *Ibid*.

41 PwC and Strategy& (2018) "Industrial Manufacturing Trends 2018-19"

42 *Ibid*.

43 Mordor Intelligence (2018) "Smart Manufacturing Industry Size - Segmented by Technology (PLC, SCADA, ERP, DCS, HMI, PLM, MES), Components (Control Device, Robotics, Communication Segment, Sensor), End-user (Automotive, Semi-conductor, Oil & Gas, Chemical & Petrochemical, Pharmaceutical, Aerospace & Defense, Food & Beverage, and Mining), and Region - Growth, Trends, and Forecast (2018 - 2023)", published in March 2018

44 PwC and Strategy& (2018) "Industrial Manufacturing Trends 2018-19"

may spin-off unneeded parts of their over-diversified product portfolio to free up capital and streamline their operations, or they may collaborate with more mature digital leaders to establish internal digital units and speed up product innovations. Companies are also keen to build a culture of resilience and speed by attracting the star talents needed to make this shift, investing in education and training of employees and fundamentally reshaping workplace culture to encourage creativity and entrepreneurship. In addition, there is an increasing emphasis on sustainability by the broader public, and this challenges manufacturers to rethink their products down to eco-materials sourcing, transparent lifecycle management and cradle-to-cradle circular design philosophy[45].

Key **customer demand trends** include[46]:

- Increasing product variety;
- Personalised products and services;
- Faster response to needs;
- Expectations of added-value services (social media interaction, order status tracking; *and*
- Societal and economic pressures to increase environmental and resource sustainability.

Specific **industry pressures and drivers** include[47]:

- Increasing need for asset and resource efficiency;
- Growing reliance on supply chain and need for robustness and tracking;
- Increasing security risks;
- Shorter product lifecycles;
- Emerging opportunities to offer value-added services throughout product life-cycle; *and*
- Increasing manufacturing complexity of products, production and data.

Furthermore, the AMT domain faces specific policy and regulatory requirements related to an **increasing demand for high quality standards, safety and sustainability**, and specifically including (among others):

- Focus on creating advanced products that have a smaller environmental impact;
- Demand for high-quality packaging and delivery; *and*
- Regulatory guidance on safety and health at work.

Automotive and Aerospace & Defense industries are leading in terms of growth for smart manufacturing solution providers, with industries such as Oil and Gas and Industrial Equipment Manufacturing rapidly upscaling their digitalisation efforts. With the spread of 3D printing, simulation, and modeling in manufacturing and design, these industries are expected to continue to maintain a significant growth rate over the forecast period of 2018 - 2023. While multiple solutions are available on the market, digital twin and real-time analytics are expected to lead the digitalisation in these industries[48].

45 World Economic Forum (2018) "Accelerating Sustainable Production"
46 UNIDO (2017) "Emerging trends in global advanced manufacturing: Challenges, opportunities and policy responses"
47 *Ibid*.
48 Research and Markets (2018) "Smart Manufacturing Market, 2025", published on 24 January 2018

While many countries have started investing in smart manufacturing, they vary considerably in terms of market maturity. Developed countries such as the United States, Germany, and Japan are demonstrating high penetration of AMT, whereas developing countries such as China are rapidly catching up with the technological advancements. An important distinction among the regional markets is that the developing countries are investing in AMT to keep up-to-date with international manufacturing standards and trends, whereas, developed economies are supporting digitalisation to bring back industrialisation. As a result, trends such as on-shoring are expected to have a profound effect on the market developments[49].

The Asia Pacific region holds a dominant position on the AMT market due to the presence of a large number of manufacturing companies stimulated by the need to compete globally[50]. The Asia Pacific is projected to remain the largest and dominant smart manufacturing market during the forecast period (2018-2023), as the region witnesses growing investments in the development of manufacturing sectors and favourable government regulations[51]. Due to the presence of a large number of manufacturing companies in China, Japan, South Korea, Taiwan, and India, these countries are the leading adopters of smart manufacturing technologies in this region. The region is expected to register highest CAGR growth for the next five years for the smart manufacturing market[52].

Various European countries including Germany, France, the United Kingdom, are also among the leading developers and adopters of smart manufacturing technologies. The North American region also holds a significant share in the overall market share in terms of revenue due to increasing adoption of AMT solutions. It is home to some of the largest multinational companies operating on the market. At the same time, Latin America, Middle East, and Africa are likely to have moderate growth for smart manufacturing market during the estimated forecast period (2018-2023)[53].

When it comes to digital transformation of manufacturing companies, Europe is currently lagging behind, as only 5 per cent of manufacturers in Europe, the Middle East and Africa (EMEA) are reported to be "digital champions," compared to 11 per cent in the Americas and 19 per cent in Asia-Pacific[54]. At the same time, Europe has strong foundations in related technology fields such as AI and cryptography, and multiple government policies are encouraging entrepreneurship with tax breaks and other measures. Dozens of national and regional initiatives for digitalising industry have been launched across Europe over the past few years[55]. Some European

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49 Grand View Research (2017) "Smart Manufacturing Market Analysis By Component, By Technology, By End-use (Automotive, Aerospace, Chemicals, Healthcare, Electronics, Agriculture, Oil & Gas), By Region, And Segment Forecasts, 2014 - 2025", published in November 2017

50 *Ibid*.

51 Zion Market Research (2018) "Smart Manufacturing Market by Technology (PLC, DCS, HMI, MES, PLM, SCADA, and Machine Vision), by Component (Hardware, Software, and Services) for Electronics, Healthcare, Automotive, Oil & Gas, Aerospace & Defense, Food & Agriculture, Industrial Equipment, Chemicals & Materials, and Others by Region (North America, Europe, Asia Pacific, Latin America, and Middle East and Africa): Global Industry Perspective, Comprehensive Analysis, and Forecast 2017-2023", published on 16 May 2018

52 Zion Market Research (2018) "Smart Manufacturing Market by Technology (PLC, DCS, HMI, MES, PLM, SCADA, and Machine Vision), by Component (Hardware, Software, and Services) for Electronics, Healthcare, Automotive, Oil & Gas, Aerospace & Defense, Food & Agriculture, Industrial Equipment, Chemicals & Materials, and Others by Region (North America, Europe, Asia Pacific, Latin America, and Middle East and Africa): Global Industry Perspective, Comprehensive Analysis, and Forecast 2017-2023", published on 16 May 2018

53 *Ibid*.

54 PwC (2018) "How industry leaders build integrated operations ecosystems to deliver end-to-end customer solutions", Digital Operations Study 2018

55 McGee P. (2018) "Europe risks falling behind in digital transformation", published in Financial Times on 5 June 2018

countries such as Germany and the Nordics now start experiencing the benefits of increased productivity gains and revenue growth due to early investments in digital technologies[56].

2.3. Overview of key labour market trends

Besides technological and market developments changing the manufacturing landscape, it is important to keep in mind also the relevant social transformations in the workforce. Examples of relevant topics include "gig economy"[57], realities of modern learners[58], the rise of millennials and other new generations, aging workforce, a changing role of women in the workforce, social learning etc. Furthermore, the developments with regard to recruitment practices and recognition need to be taken on board too (e.g. recruitment based on potential rather than qualifications; recruitment for access to people who can do the work rather than an ability to perform work directly; open badges; evolving role of employment agencies etc.). While the current sub-section does not aim to address all relevant labour market developments, we aim at highlighting some of the most prominent ones.

Specific relevant **labour market trends** include the following[59]:

- A shift towards **diversified and more highly skilled workforce**: diversity is driving today's workforce with an increasing role of women, students working to fund their education, people with disabilities, self-employed people returning to work, pensioners wishing to keep a professional activity etc. When it comes to education, research conducted in OECD countries[60] shows that access to education continues to expand, with more and more people having tertiary education.
- A shift towards **flat and globalised workforce**: by 2025, when China is forecasted to be home to more large companies than either the United States or Europe, it is expected that nearly half of the world's large companies (those with revenue of 1 billion USD or more) will be headquartered in emerging markets[61].
- An overall **ageing global working population**: people live longer and work while being older, and migration is reaching levels not seen for decades, allowing to partially bridge the talent gap. A smaller workforce will place a greater pressure on productivity for driving growth. Caring for large numbers of elderly people will put severe pressure on public sector budgets.

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56 McGee P. (2018) "Europe risks falling behind in digital transformation", published in Financial Times on 5 June 2018

57 i.e. a free market system in which temporary positions are common and organisations contract with independent workers for short-term engagements; more information available at: https://whatis.techtarget.com/definition/gig-economy

58 It is crucial to keep in mind the realities in which modern learning occurs, including learners' jobs, habits, behaviours and preferences. An infographic developed by Bersin in 2015 (see Bersin (2015) "Meet the modern learner" infographic, available at: https://mrmck.wordpress.com/2015/06/19/meet-the-modern-learner-infographic/) emphasised that today's employees are overwhelmed, distracted and impatient. Flexibility in what, where and how they learn becomes increasingly important. Modern learners want to learn from their peers and managers as much as from experts. They are taking more control over their own development. An estimate was made that 1% of a typical workweek is all that employees have to focus on training and development. The abovementioned realities have direct implications for on-the-job training and indicate the agility of modern learning, decentralisation of training activities and a growing importance of informal learning.

59 WEC (2016) "The future of work: White paper from the employment industry", World Employment Confederation Europe, September 2016

60 OECD (2014) "Education at a glance"

61 McKinsey & Company (2015) "The Four Global Forces Breaking All the Trends", cited in WEC (2016) "The future of work: White paper from the employment industry", World Employment Confederation Europe, September 2016

- A shift towards an **urban working population**: more than 50% of the population today live in a city, and the growth of population living in urban area is predicted to continue in the years to come.
- A shift towards a **hyper-connected workforce**: the definition of 'the workplace' is changing, going beyond physical work premises to include anywhere the worker goes in the performance of his/her duties. As a result, work is no longer a place to go but a task to perform.
- A shift towards **different working arrangements**: being employed as a full time worker with permanent wage should not be seen as the standard way of working anymore. Other working arrangements such as part-time work, self-employment, art work, family work, teleworking, crowd working, user work, informal work, free work etc. become increasingly popular. Part of this diversification of work relationships stems from the rise of multi-activity at work, i.e. portfolio workers holding several jobs and multiple income sources at the same time.

The abovementioned developments lead to[62]:

- The emergence of a wide variety of employment situations[63];
- The rise of new forms of work outside the employment relationship;
- Growing individual expectations and diverse working conditions;
- The transformation of workplaces, times and activities;
- The emergence of multifaceted and discontinuous career paths;
- Increasing interconnections between work and private life;
- The rise of agile and dynamic labour markets; *and*
- Fading boundaries between national labour markets.

With regard to the labour market trends specifically in AMT, the report of the Word Economic Forum (WEF)[64] suggests that the expected global decline in total Manufacturing and Production roles is driven by labour-substituting technologies such as additive manufacturing and 3D printing, as well as by more resource-efficient sustainable product use, lower demand growth in ageing societies and threats to global supply chains due to geopolitical volatility. The rise of robotics, however, is predicted to lead to labour-complementing productivity enhancement rather than pure job replacement.

3D printing, resource-efficient sustainable production and robotics are forecasted to be strong drivers of employment growth in the Engineering job family, signifying a continued and fast-growing need for skilled technicians and specialists to create and manage advanced and automated production systems. This is expected to lead to a **transformation of manufacturing into a highly advanced sector where high-skilled engineers are in strong demand[65]**.

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62 WEC (2016) "The future of work: White paper from the employment industry", World Employment Confederation Europe, September 2016

63 Since the technology makes physical and organisational boundaries increasingly blurred, organisations will have to become significantly more agile in managing people's work and thinking about the workforce as a whole. Companies will increasingly have to connect and remotely collaborate with freelancers and independent professionals through digital talent platforms. That is likely to lead to the emergence of new forms of labour associations such as digital freelancers' unions. Governments will need to develop new/updated labour market regulations to facilitate these new organisational/business models. Based on WEC (2016) "The future of work: White paper from the employment industry", World Employment Confederation Europe, September 2016

64 WEF (2016) "The Future of Jobs"

65 *Ibid*.

Installation and Maintenance jobs, in turn, are predicted to witness great productivity enhancements and strong growth in green jobs such as the installation, retrofitting, repair and maintenance of smart meters and renewable energy technologies, but they will also have to face the efficiency-saving and labour-substituting aspect of Industry 4.0[66].

Furthermore, there is still a strong misconception among students and broader public when it comes to the image of the manufacturing domain. The latter is associated with poor working conditions and lack of prestige[67]. Based on the data by Glassdoor[68], manufacturing jobs are often perceived to be repetitive, monotonous, underpaid, and involve working in decrepit, dirty factories. Another popular misconceptions refer to the inability of manufacturing to offer a viable, satisfying career or to be financially rewarding. Younger generations urgently need to be convinced about the promising opportunities for them within the manufacturing domain, from professional growth to dynamic learning environments to competitive compensation[69].

With regard to generational factors, **Millennials** are predicted to comprise 75 percent of the global workforce by 2025[70]. According to Sodexo 2017 Global Workplace Trends[71], this new generation generally seeks a bigger purpose in life, is highly educated, and represents natural innovators. They are particularly motivated by human contact, continuous feedback, training & development and flexibility. These all are highly relevant characteristics when it comes to meeting the abovementioned skills needs of the 21st Century. At the same time, Millennials in general do not seem to possess all the relevant characteristics to meet the 21st Century needs, and specifically **critical thinking is often reported to be lacking**[72]. They are often referred to as "overeducated, but underskilled". Additionally, Millennials tend to demonstrate a lack of loyalty to their employers. According to Glassdoor, the jobs millennials prefer, or at least apply for most frequently, tend to be high-paying occupations that demand experience dealing with software, data or management[73]. The most demanded jobs include among others software engineer, data analyst, data scientist, business analyst and administrative assistant.

Nevertheless, the abovementioned generalisations need to be treated with caution, as belonging to a certain generation represents only one of many diverse factors influencing the behaviour of specific individuals.

66 WEF (2016) "The Future of Jobs"

67 The first expert workshop on "Aligning Advanced Manufacturing education and training with the 21st Century needs: Higher Education", held in Brussels on 12 June 2018

68 Glassdoor is a website where current and former employees anonymously review companies: https://www.glassdoor.com

69 Barr K. (2018) "Manufacturing Has a Serious Image Problem", Industry Week, 24 October 2018

70 https://www2.deloitte.com/content/dam/Deloitte/global/Documents/About-Deloitte/gx-dttl-2014-millennial-survey-report.pdf

71 https://www.sodexo.com/home/media/publications/studies-and-reports/2017-workplace-trends/unlocking-millennial-talent.html

72 See, for example, MindEdge (2017) "Online Survey of Critical Thinking Skills"

73 Renzulli K.A. (2019) "The job millennials want most pays $98,500 - here are the other 9", CNBC, 21 February 2019

3. KEY NEEDS IN TERMS OF SKILLS, EDUCATION AND TRAINING

The developments presented in the previous chapter have **direct implications for skills**. The evolving skill requirements, in turn, require **reconsidering the current approaches towards education and training** of manufacturing professionals. In general, there is a need for creating hands-on opportunities within education systems; close collaboration of business and educational institutions; offering learners real-world experience, exposing them to real challenges and advancements of industry; focussing on real-world application of skills, and developing and elevating micro-credentialing programs for students and workers. In the current chapter, we zoom into the key needs in terms of skills, education and training.

Specific **motivation** to engage in upskilling/reskilling activities varies per stakeholder level (see Figure 1-1). At the *micro-level*, learners need to upskill/reskill themselves in order to maintain/gain the desired careers, while teachers' motivation is related to actually providing high-quality education and training that offers true added value in the new industrial age. At the *meso-level*, the primary motivation is often linked to maintaining/gaining the reputation of an institution that provides high-quality education and training in line with the needs of the new industrial age, and for industry, the primary motivation is linked to maintaining/increasing the competitiveness of a company by advancing its talent. Finally, at the *macro-level*, the actions are driven by the desire to achieve/maintain the competitiveness of a specific country or Europe as a whole. While stakeholder groups at different levels have different motivations, they are all united by a common need to address the upskilling/reskilling activities, and to put it as a key priority in their agendas.

3.1. Key needs in terms of skills

In this sub-section, we first address the skill requirements for high-tech professionals in general, and then specifically look into the key needs in terms of skills for "Manufacturing professionals 4.0".

3.1.1. Skill requirements for high-tech professionals

An extensive analysis of skill requirements for high-tech professionals has been performed by PwC in the context of the "Vision and Sectoral Pilot on Skills for Key Enabling Technologies" initiative (2014 – 2016) (hereafter "KETs Skills Initiative") for DG GROW of the European Commission[74]. KETs professionals here refer to all key groups of workers active in KETs domains, that broadly speaking comprise operators, technicians, engineers and managers. When the KETs Skills Initiative was carried out, KETs included Micro-/Nanoelectronics, Nanotechnology, Photonics, Advanced Materials, Industrial Biotechnology and Advanced Manufacturing Technologies[75].

74 PwC (2016) "Final report on Vision and Sectoral Pilot on Skills for Key Enabling Technologies", prepared for DG GROW of the European Commission, Service contract nr. SI2.ACPROCE060233200

75 In line with the initial definition of the Commission's Staff Working Document "Current situation of Key Enabling Technologies in Europe" SEC(2009) 1257. In the meantime, the definition of KETs by the European Commission has been adjusted. KETs currently include Materials and Nanotechnology, Photonics and Micro- and Nano-electronics, Life Sciences Technologies, Artificial Intelligence, Digital Security and Connectivity (based on the report from the High-Level Strategy Group on Industrial Technologies (2018) "Re-finding industry", Conference document, 23 February 2018).

The state-of-the-art skills research, as well as prominent frameworks on skills[76], suggest that the notion of skills goes hand in hand with the notions of competency, knowledge, attitudes and values[77].

Skills are usually used to refer to a level of performance, in terms of accuracy and speed of performing particular tasks. Skills can be defined as a goal-directed, well-organised behaviour that is acquired through practice and performed with economy of effort[78].

Knowledge includes theory and concepts, as well as tacit knowledge gained as a result of the experience of performing certain tasks. The notion of knowledge is linked to the concept of understanding. Understanding refers to more holistic knowledge of processes and contexts and may be distinguished as know-why, as opposed to know-what[79].

Competency, in turn, can be defined as one's capability to handle certain situations successfully or complete a job[80]. Competency can thus be considered an umbrella term for being equipped with the relevant knowledge and skills to be able to carry out the tasks and duties of a certain job. The term 'competency' implies more than just the acquisition of knowledge and skills; it involves the mobilisation of knowledge, skills, attitudes and values to meet complex demands[81].

The following six categories of KETs competencies were identified by PwC[82]:

(1) **Technical**: competencies related to practical subjects based on scientific principles (e.g. programming, computational thinking, mathematical modelling and simulation, top-down fabrication techniques etc.);
(2) **Quality, risk & safety**: competencies related to quality, risk & safety aspects (e.g. quality management, computer-aided quality assurance, quality control analysis, emergency management and response, industrial hygiene, risk assessment etc.);
(3) **Management & entrepreneurship[83]**: competencies related to management, administration, IP and finance (e.g. strategic analysis, marketing, project management, R&D management, IP management);

76 For example, OECD Learning Framework 2030, European Qualifications Framework, European e-Competence Framework; analysis by CEDEFOP (2006) "Typology of knowledge, skills and competences: Clarification of the concept and prototype", CEDEFOP reference series.
77 PwC (2016) "Final report on Vision and Sectoral Pilot on Skills for Key Enabling Technologies", prepared for DG GROW of the European Commission, Service contract nr. SI2.ACPROCE060233200
78 CEDEFOP (2006) "Typology of knowledge, skills and competences: Clarification of the concept and prototype", CEDEFOP reference series.
79 *Ibid*.
80 Ellstrom P. E., Kock H. (2009) "Competence development in the workplace: concepts, strategies and effects" in Illeris K. (2009) "International Perspectives on Competence Development. Developing Skills and Capabilities". London: Routledge, cited in Chryssolouris, G., Mavrikios, D., & Mourtzis, D. (2013). Manufacturing Systems: Skills & Competencies for the Future. Procedia CIRP, 7, 17-24.
81 OECD (2018) "The Future Education and Skills: Education 2030"
82 PwC (2016) "Final report on Vision and Sectoral Pilot on Skills for Key Enabling Technologies", prepared for DG GROW of the European Commission, Service contract nr. SI2.ACPROCE060233200
83 The estimates of PwC (2017) suggested that that out of the 953,000 additional KETs professionals in demand between 2013 and 2025, 85,770 additional leaders will be needed up till 2025 (see empirica & PwC (2017) "Leadership Skills for the High-Tech Economy (SCALE)", Final Report for EASME/DG GROW of the European CommissionWhile these numbers refer to the leaders of business divisions, departments and companies, it is important to point out that leaders can be found at different company levels, including team/project leaders. Therefore, the need for leadership (including management and entrepreneurship) competencies for KETs is broader than for the formal layer of managers only.

(4) **Communication**: competencies related to interpersonal communication (e.g. verbal communication, written communication, presentation skills, public communication, virtual collaboration);
(5) **Innovation**: competencies related to design and creation of new things (e.g. integration skills, complex problem solving, creativity, systems thinking); and
(6) **Emotional intelligence**: the 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).

Many of these categories are similarly echoed in similar reports by industry think tanks. For example, The World Economic Forum suggests that the top ten skills to thrive in the coming decade, given the threat of employment disruptions from automation and AI, include the following[84]:

(1) Complex problem-solving;
(2) Critical thinking;
(3) Creativity;
(4) People management;
(5) Coordinating with others;
(6) Emotional intelligence;
(7) Judgement and decision-making;
(8) Service orientation;
(9) Negotiation;
(10) Cognitive flexibility.

The skills above do not touch on any technical skills explicitly; however, this can be explained by the fact that technical skills are domain-specific and hence irrelevant for a list of universal skills that all workers should develop for the future economy. The ten skills above do however fall into many of the other six categories highlighted in the PwC analysis.

High-tech domains rely on a balance of both technical and non-technical competencies. Technical competencies can be considered the 'heaviest' category in terms of required knowledge and skills due to a highly knowledge-intensive nature of high-tech domains. However, the competencies needed to successfully operate within these domains go far beyond the technical field and also cover a wide range of non-technical/transversal areas. These non-technical competency areas include competencies related to quality, risk & safety; management & entrepreneurship; communication; innovation-related competencies and emotional intelligence.

With regard to quality, risk & safety, the high-tech domains represent an environment where **workers need to operate with a high level of accuracy** as the equipment is highly expensive, and errors are costly. This accuracy requires a specific mind-set, the ability to concentrate over a long period of time, attention to detail, and the ability to work in an environment with stringent and specific quality and safety procedures. This type of competency is relevant to all professionals involved in manufacturing, and particularly to factory floor workers.

The complex commercialisation and implementation trajectories within high-tech domains, including high-risk product demonstration and proof-of-concept projects,

84 Desjardins J. (2018) "10 skills you'll need to survive the rise of automation", World Economic Forum

also heavily rely on **advanced management competencies**. The latter include market analysis and strategy development in a chaotic and unpredictable environment, the need to acquire and manage large investments due to highly capital-intensive nature of the high-tech domains, the need to coordinate multidisciplinary international teams, the need to manage complex processes with high risks and strict deadlines etc.

Given the importance of teams in the high-tech domains (which are typically formed from people with diverse professional and cultural backgrounds), **communication-related competencies** represent another key competence category. Communication here refers to all kinds of interpersonal exchange of information, including verbal and written communication, but also virtual collaboration or communication in virtual teams. The latter refers to the ability to work productively, drive engagement and demonstrate presence as a member of a virtual team.

Innovation competencies refer to the ability of high-tech workers to use and integrate various disciplines into joint solutions to complex problems, the ability to find new patterns and connections between multiple fields, where these patterns and connections have never been found before. Innovation competencies are central for the high-tech domains, the very nature of which is defined by their multi-disciplinarity and (potential) connection to an endless number of application areas.

Finally, **emotional intelligence** is related to the ability to operate with own and other people's emotions, and to use emotional information to guide thinking and behaviour, including the use of intuition or so called 'gut feeling' about market-related and other developments. Emotional intelligence emphasises the central role of human aspects in innovation.

Competencies that need to be possessed by the high-tech professionals can be split in two broad categories: **general and specific competencies**. General competencies here refer to the ones that are common for the majority of high-tech workers, independently of the respective field, employer or a specific job profile. These competencies thus represent a 'common core' of skills and knowledge that need to be present in people to enable them to act successfully within the high-tech domains. Specific competencies, in turn, are unique to a particular domain, employer and/or a specific job profile. These competencies, for example, refer to a highly specialised technical knowledge, but also to skills of working with specific equipment, as well as an in-depth knowledge of non-technical fields (e.g. specific legislation, specific sales techniques, detailed quality assurance principles etc.)[85]. Furthermore, a highly complex multidisciplinary nature of the high-tech domains requires intensive **teamwork** and active **collaboration** of multiple people/teams/organisations simultaneously. The abovementioned competencies should by no means be viewed as a must-have list for every single professional. The required competencies can be to a different extent present in different individuals, that, in turn, need to work together and complement each other. The high-tech domains thus heavily rely on 'smart' combinations of people with a wide range of profiles, with many of them coming from domains not directly related to high-tech, particularly when it comes to specific application areas[86].

85 For more information on the distinction between general and specific KETs competencies, the reader is advised to consult PwC (2016) "Final report on Vision and Sectoral Pilot on Skills for Key Enabling Technologies", prepared for DG GROW of the European Commission, Service contract nr. SI2.ACPROCE060233200

86 PwC (2016) "Final report on Vision and Sectoral Pilot on Skills for Key Enabling Technologies", prepared for DG GROW of the European Commission, Service contract nr. SI2.ACPROCE060233200

Another question that may arise here is about the ratio of technical to non-technical skills that would be appropriate for future professionals. It would be preferable to see technical and non-technical skills as equally important and complementary, rather than a zero-sum game where time spent learning a non-technical skill implies lesser time to learn technical skills. For example, not everyone in the team needs to be equally technically skilled in exactly the same domain for the team to be successful. Instead, an appropriate distribution of technical skills across multiple domains *plus* a healthy amount of leadership, collaboration, cultural awareness, creative association and/or emotional intelligence can elevate a good team into a great team. Non-technical skills should thus not be seen as optional nice-to-haves but as a fundamental part of the operating system required for successful collaboration.

In addition, non-technical skills should also not be viewed as static strengths and weaknesses that remain the same per individual in every social context. Rather, they should be seen as dynamic notions that change relative to the context of the problem at hand and the specific combination of personalities within the team. For example, the brainstorming phase of a project might be led by more creative individuals in the team whereas the more structure-oriented members could take over when time or budget constraints necessitate quick and decisive actions.

3.1.2. Manufacturing professionals 4.0

The "Manufacturing professionals 4.0" here refer to all key groups of workers of the Advanced Manufacturing domain, that broadly speaking include operators, technicians, engineers and other relevant professionals (computer coders, app developers, data scientists, 3D printing specialists etc.) and managers.

According to the VDI White Paper (2015)[87], in order to derive skills and qualifications of the future manufacturing professionals, there is a need to consider three distinctive tiers (with Tier 3 forming the base for Tier 2, and Tiers 2 and 3 jointly forming the base for Tier 1):

- **Tier 3**: including factors that have a considerable influence on the workforce in a factory of the future, such as tools & technologies; organisation & structure; working environment, intraorganisational and interorganisational cooperation;
- **Tier 2**: Tasks;
- **Tier 1**: Skills and qualifications.

Within **Tier 3**, when it comes to **tools & technologies**, the "factory of the future" implies:

- a decreasing need to perform manual and routine tasks;
- access to real-time information on a certain situation to perform a task efficiently;
- worker's ability to control and monitor production processes through the analysis of data and information supported with devices;
- optimised human machine interfaces allowing the worker to make qualified decisions in a shorter time; and
- active use of collaborative robotics.

87 VDI (2015) "A Discussion of Qualifications and Skills in the Factory of the Future: A German and American Perspective", April 2015, White Paper by the Association of German Engineers, with support of ASME American Society of Mechanical Engineers

The observed change in the organisational structure refers to a decreasing need for workers to be bound to a certain production area, which leads to improved possibilities of job rotation and job enrichment. In addition, the factory of the future implies larger responsibility and more decision-making power; a mix of short- and long-term teams; and an ecosystem in which problem solving is done in collaboration with all participating parties on the shop floor and without much influence of a higher hierarchy. The latter signifies the transition towards a flat organisation structure.

The future **working environment** for AMT professionals is anticipated to represent a more open, clean, and creative space. It is associated with improved ergonomics (due to automation of dangerous and hazardous jobs); active use of devices and assistance systems; and larger flexibility with respect to shifts or working day. The latter would lead to more transparent work planning, improved work-life balance, emergence of entirely new shift modes (no need to stand at one specific production station for the course of the entire shift), and opportunity to work from home.

The **intraorganisation and interorganisational cooperation** implies more teamwork, more cooperation, and more communication. The "factory of the future" is associated with accelerated learning curves within production networks due to access to all kinds of information and data, and an opportunity to organise workshops, seminars, and training sessions within the cyberspace. Communication does not only happen with humans but also with other elements of cyber-physical systems, such as robots, machines, or the actual product. Service providers become increasingly able to access robotics systems in a manufacturing plant from outside the factory to perform service updates or react to errors right away. Increased collaboration can be observed with external parties and specifically research institutes, universities, and parties that are not classical suppliers, due to the interdisciplinary character of digital production.

The abovementioned developments signify changes in the associated **tasks (Tier 2)**, and specifically lead to a greater task variety and the need for more qualified work. Monotonous and ergonomically challenging tasks are expected to decrease to a minimum due to automation. Tasks heavily based on data and information processing will be dominating, signifying a shift from material flow to information flow. Tasks will be mainly performed through devices and assistance systems.

The changes in tasks lead to **changes in the required qualifications and skills (Tier 1)**. Key technical skills that are expected to be gaining importance include knowledge/data management skills; multi-disciplinary understanding of organisation, its processes and used technologies; IT security and data protection; proficiency in methodologies for real-time decision making (UNIDO, 2017); as well as computer programming or coding abilities or similar deep technical knowledge (useful but not compulsory). Key non-technical skills for the factory of the future include adaptability/flexibility, communication skills, teamwork skills, self-management, and a general mind-set for continuous improvement and lifelong learning.

Similar conclusions have been made by the recent 2018 skills gap study[88] from Deloitte and The Manufacturing Institute, analysing the situation in the U.S.[89]. The top five identified skill sets that could increase significantly in the coming three years due to automation and advanced technologies include technology/computer skills, digital

88 Deloitte and The Manufacturing Institute (2018) "2018 Deloitte and The Manufacturing Institute skills gap and future of work study", Deloitte and The Manufacturing Institute series on the skills gap and future of work in manufacturing

89 Crowe S. (2018) "Skills gap worsening in US manufacturing industry", published on 21 November 2018 in The Robot Report

skills, programming skills for robots/ automation, working with tools and technology, and critical thinking skills[90].

The abovementioned findings were supported by the key outcomes of the online survey carried out in the context of this initiative in December 2018. In total, about 170 responses were collected from education and training providers, policy makers, companies and supporting organisations from all over Europe.

According to the survey respondents, the top three most important technical skills for the manufacturing professionals in the years to come include the ability to interact with human-machine interfaces (18%), data management skills (16%) and specialised knowledge of technologies and processes (16%). These findings confirm fundamental implications for the skill needs caused by the digital transformation of the manufacturing domain. As for the non-technical skills, the most important ones refer to adaptability/flexibility (19%), critical thinking (15%), creativity (13%) and general mind-set for continuous improvement and lifelong learning (13%). It is no longer mainly about what a person knows, but increasingly about if this person is able to adapt to continuously changing circumstances and constantly advance his/her knowledge and skills.

The Highlight below clusters the abovementioned skill requirements into five distinctive but interconnected components of the target profile for Engineers for Industry 4.0.

Highlight 3-1: The target profile for Engineers for Industry 4.0[91]

The target profile for Engineers for Industry 4.0 has five components:

(1) **Basic specialist knowledge** in an engineering discipline;

(2) **Methodological skills**, especially process-related and systems thinking;

(3) **Cross-discipline knowledge** such as mechanical, electrical and electronic engineering in computer sciences and data science, and respectively, basic knowledge of mechanical, electrical, and electronic engineering and data science for computer sciences;

(4) **Contextual knowledge**, i.e. knowledge of conditions, requirements, and perspectives in other divisions and disciplines; *and*

(5) **Interdisciplinary skills**, especially the ability to work in a team, self-sufficiency, motivation, problem-solving skills, the ability to learn and adapt, openness, and communication skills.

The profile heavily relies on the specialist requirements in the various engineering disciplines, with new additions being skills in computer sciences, data science, and data security. Furthermore, Engineers for Industry 4.0 need to be able in their own work to take into account points of view from other disciplines. Methodological skills, especially process thinking and systems thinking, and interdisciplinary skills, such as the ability to work both self-sufficiently and within a team, as well as the ability to learn and adapt are therefore crucial. However, these skill requirements do not imply a need for "super-engineers." The elements in the target profile do not need to be possessed by all engineers to the same extent, as the extent will vary depending on the area of specialisation.

90 Crowe S. (2018) "Skills gap worsening in US manufacturing industry", published on 21 November 2018 in The Robot Report

91 Impuls Foundation (2019) "Impuls compact: Engineers for Industrie 4.0", VDMA (The Mechanical Engineering Industry Association), March 2019

3.2. Key needs in terms of education

While the industry sector has drastically changed over the last two decades, the education and training systems including their curricula have not evolved at the same pace. Stakeholders report that VET/university graduates are not immediately employable; they need to go through long, time- and money-consuming training process in companies before they can start executing tasks independently[92].

While there are already some effective approaches towards adapting engineering training to Industry 4.0, many education providers only now begin to consider the necessary development. Reshaping curricula is a considerable challenge, implying complex decision-making processes. In addition, administrative obstacles make it difficult to organise study programs across faculties and departments. Many departments and faculties are dominated by subject-related 'silo thinking', while promising approaches require intensive networking, especially in teaching[93].

3.2.1. Key areas of mismatch

Figure 3-1 provides an indication of the **key areas of mismatch** when it comes to the key skill requirements presented in the previous sub-section.

Specifically, the current educational programs focus mainly on technical skills, while professionals involved in KETs/AMT need to demonstrate **an adaptive blend of both technical and non-technical skills**. Nowadays, given continuous changes in business, cultural, legal and market environments, the 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.[94].

In terms of technical skills, **students often have to work with the software and equipment that are outdated, without having access to the state-of-the-art developments**. In terms of non-technical skills for technical people, educational programs in general do not pay sufficient attention to leadership skills, quality management for complex products and processes, innovation and entrepreneurship skills, as well as marketing and sales skills for KETs/AMT.

Additionally, the current educational programs often focus on teaching facts and problem-solving skills in a series of narrow topics, while KETs/AMT require a **multidisciplinary approach** implying knowledge of at least the outlines of every field of life that might be relevant to the possible application areas. Consequently, new ways of teaching are needed going beyond the traditional 'silos' approach and training the ability to see linkages between previously unconnected fields. Furthermore, educational programs also often do not sufficiently train **the ability to apply theoretical knowledge to real industrial problems**, while it is one of the most desirable attributes in new KETs recruits.

92 CECIMO (2013) The European machine tool industry's Manifesto on skills, September 2013
93 Impuls Foundation (2019) "Impuls compact: Engineers for Industrie 4.0", VDMA (The Mechanical Engineering Industry Association), March 2019
94 *Ibid*.

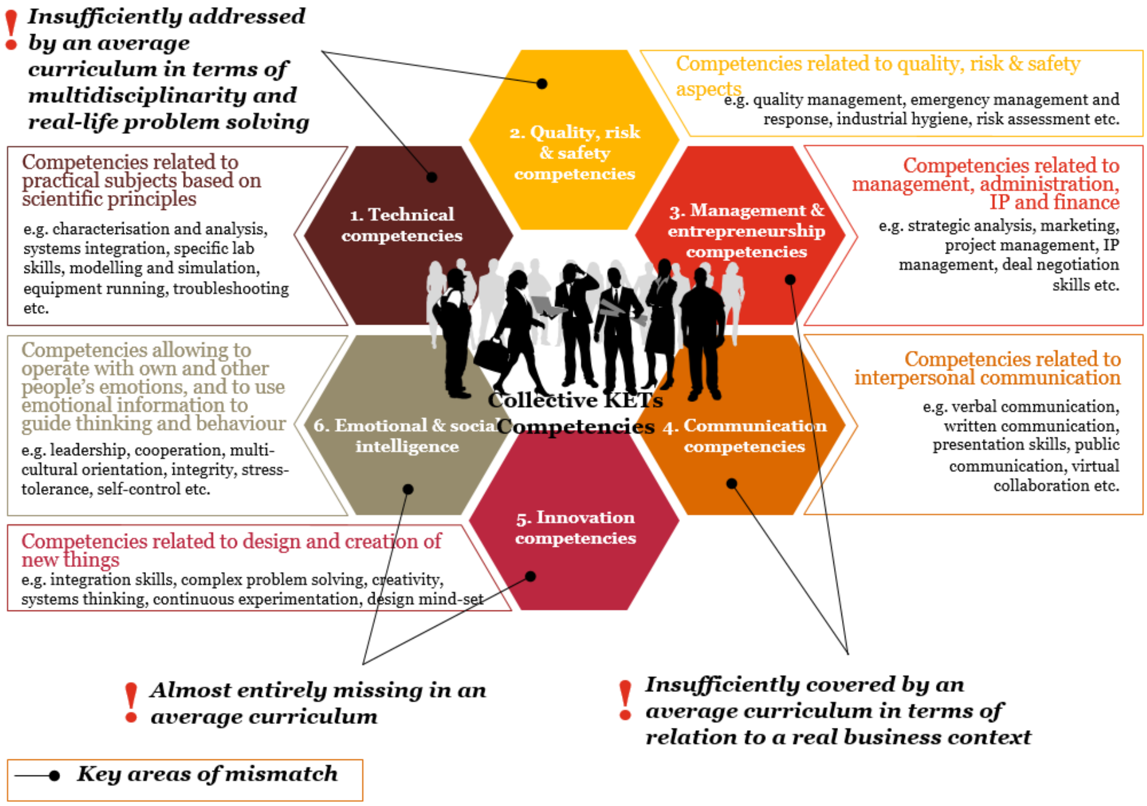


FIGURE 3-1: Collective KETs competencies and key areas of mismatch (source: PwC[95])

Finally, the current educational programs often fail to achieve **the right balance between the depth of knowledge within a discipline and breadth across disciplines** (general vs. specific knowledge and skills or *T-shaped approach*[96]). According to the stakeholders, there is no need for 'one size fits all' approach, i.e. there is a clear need for diversity in the degree of specialisation among students and workers. In general, large companies tend to prefer graduates with a higher degree of specialisation, while SMEs look for people with a more general set of skills (but still with the relevant academic background).

Certain diversity in terms of general vs. specific knowledge and skills can also be observed between specific KETs, for example, with nanotechnology workers having a more general orientation and materials professionals having a more distinct specialisation. The abovementioned diversity should therefore also be reflected in the educational approaches.

3.2.2. Teaching new skills and teaching skills in a new way

In fact, in their essence, **many of the skills that AMT professionals need in the 21st century are not that new**. Critical thinking, problem solving, global awareness, the need to master different kinds of knowledge, innovation etc. have all been components of human progress throughout history[97].

Many stakeholders argue that with so much new knowledge being created, content no longer matters. Knowing where to find information are now much more important than

95 Based on PwC (2016) "Final report on Vision and Sectoral Pilot on Skills for Key Enabling Technologies", prepared for DG GROW of the European Commission, Service contract nr. SI2.ACPROCE060233200
96 See, for example, T-Summit that was held in Washington DC (USA) in 2016
97 Based on Rotherham A.J. and Willingham D. (2009) "21st Century Skills: The Challenges Ahead"

information itself. The discussion, however, is not about content vs. skills. Skills and content are not separate, but intertwined. It is about how to meet the challenges of delivering content and skills in a way that effectively improves outcomes for students, employees and employers. **There is a need to teach skills in the context of particular content/knowledge and to treat both as equally important**[98].

Lifelong learning also implies some level of blurring between theoretical and vocational training, to be independent of the academic background of the learner. For example, a learner with a Master degree may pursue a vocational course to pick up a specific skillset where needed, and conversely a learner with a VET diploma may receive some theoretical lectures to boost his/her knowledge where needed. The choice of the course type would thus depend mostly on the task at hand and the knowledge/skills required to perform that task well, and not on the academic history of the individual prior to taking the course.

In addition, education leaders need to be realistic about **which skills are teachable**. Making skills such as, for example, collaboration and self-direction a mandatory part of the study does not yet mean that learners will actually be learning them. There needs to be clarity on which methods and techniques are best in training these skills in students and workers[99]. In this respect, the potential of **technology-enabled learning tools** (e.g. e-learning, including MOOCs, m-learning, gamification, augmented reality etc.) and related learning concepts (e.g. learning factory, blended learning, DIY [Do-It-Yourself] etc.) need to be explored. Special attention needs to be paid to the educational approaches when implementing these tools.

3.2.3. Key directions for action

Within the KETs Skills Initiative[100], together with stakeholders, we have identified the following key directions for action aiming to tackle the identified qualitative skills challenges:

- **Embedding technical multidisciplinarity in the curriculum**: training students in various disciplines simultaneously so that they can work 'on the crossroads' of those disciplines (e.g. mechatronics combining mechanics, electrics and systems engineering);
  - o In order to ensure multidisciplinarity in education, a concept of **'dual learning'**[101] could be promoted, at least for vocational education. Dual learning implies combining education with work experience, thereby acquiring experience in an actual manufacturing environment before entering the labour market.
- **Embedding non-technical courses into the curriculum**: offering non-technical courses for technical students in the areas of quality, risk & safety; management & entrepreneurship; communication; innovation-related competencies and emotional intelligence skills;

98 Based on Rotherham A.J. and Willingham D. (2009) "21st Century Skills: The Challenges Ahead"
99 *Ibid.*
100 From PwC (2016) "Vision Report: Vision for the development of skills for Key Enabling Technologies (KETs) in Europe", developed for DG GROW of the European Commission
101 Also known as alternate education (e.g. 6 months in classrooms and 6 months in industry). Research shows that students which followed such alternate education have better job opportunities when entering the market.

  - **Adding Arts to the curriculum**: competencies coming from STEM are not sufficient for KETs. KETs require STEAM[102], with Arts included, which refers to creativity that can lead to innovations. Arts and creativity therefore should also be embedded in technical curricula.

- **Offering problem-based learning**: building the curricula with an aim of training problem-solving mind-sets, i.e. training an ability to think and act from a perspective of a problem, approaching the same problem from various angles, taking risks with approaches and solutions that have never been applied or attempted before and continuously striving to improve upon a current situation or condition; the problem-based learning needs to be linked to *real-life problems*.

- **Updating the skills of teachers/professors**: sending the educational personnel to companies to get insights into the latest developments, while inviting people from companies to regularly teach in the classroom;

- **Promoting innovation in teaching (including technology-enhanced learning)**: rewarding educational institutions and teachers/professors for introducing innovative approaches; these aspects need to be embedded in the assessment schemes for both organisations and individuals;

- **Organising collective training programs and apprenticeships**: joining forces with other companies and educators, as well as other relevant stakeholders) to offer training programs to the KETs professionals that would result in certificates recognised throughout the industry; etc.

When further developing the key directions for action and curriculum guidelines, it is important to keep in mind that **learning is a continuous process**. Formal education of KETs/AMT professionals (including VET and higher education) is 'just' a step in the **life-long learning** trajectory. It needs to be complemented by regular on-the-job training (both formal and informal), and thus needs to be considered in the broader context of continuous learning, happening both *individually and collectively* (teams, companies, networks of companies etc.).

3.2.4. Designing a new curriculum framework

A new approach towards education and training implies designing a new curriculum framework. The latter, in turn, needs to create the educational culture and learning environment that would lead to the development of highly skilled, emotionally intelligent, innovative and flexible KETs and AMT professionals, fit to tackle the challenges of the 21st century.

Based on our experience of working with multiple stakeholders in the field of KETs and AMT, as well as in the area of education and training, some of the illustrative key principles of this new curriculum framework would (at least) include elements of:

(1) **Student-centred approach**: students/learners need to be put at the centre of the curriculum design, in order to cultivate their intrinsic motivation and to foster life-long learning:
  - Engaging students in designing their learning programmes;
  - Engaging students in assessing their own progress and experience;

102 For more information, see: http://steam-notstem.com/

- Engaging students in assessing teachers' performance[103].

(2) **Multidisciplinary orientation**: enhancing the KETs-/AMT-related technical courses with the elements that stimulate analytical and critical thinking, creativity, business, entrepreneurship, employability, and social and ethical perspectives for science and technology.

(3) **Problem (challenge)-driven learning**: stimulating students to work on difficult real-life problems and challenges for which there are no established answers; this approach allows students to contextualise their theoretical learning in relation to how it would be useful in the world around them.

(4) **Collaborative (collective) learning**: encouraging collaborative working in multidisciplinary teams, fostering the development of communication skills;

(5) **Technology-enabled learning**: encouraging the use of technology and software applications for learning (e.g. MOOCs, m-learning, gamification, augmented and virtual reality, AI etc.).

(6) **Experience-based learning**: facilitating the acquisition of hands-on experience:
- building projects and problems around real-life cases and stimulating the acquisition of hands-on experience, engaging companies in providing cases and facilities;
- incorporating work placements/apprenticeships (acquiring real work experience) into the curriculum;
- engaging employers and professional organisations in curriculum development;
- combining academic staff and industry practitioners.

(7) **Continuous learning (cultivating life-long learners)**: recognising that formal education is only part of the continuous learning trajectory; encouraging the use of other informal types of learning including open-source learning and extra-curricular activities; providing students with skills and tools to continue their own upskilling throughout their career (life-long learning).

(8) **Learning ecosystem approach**: connecting learners to employers and other key stakeholders through project work, industrial placements, matchmaking events etc.

3.2.5. Implications for teacher training

The abovementioned approaches are already widely recognised and can be found in many pedagogical methods textbooks for VET and HE. **Teachers know about them and believe they are effective. However, teachers hardly use them**[104].

These approaches require teachers to be knowledgeable about a broad range of topics and be prepared to make in-the-moment decisions as the lesson plan progresses. They make the classroom management much more challenging. One of the ways to support teachers in implementing these approaches is to facilitate their collaboration and enable them to share their experiences[105].

Existing research suggests that **many teachers do not need to be convinced that innovative approaches to learning are a good idea – they already believe**

103 This issue is, however, a matter of debate as there is currently no correlation between student evaluation of teaching and student performance. See, for example, Henry A. Hornstein & Hau Fai Edmond Law (2017) "Student evaluations of teaching are an inadequate assessment tool for evaluating faculty performance", Cogent Education, 4:1, DOI: 10.1080/2331186X.2017.1304016

104 Based on Rotherham A.J. and Willingham D. (2009) "21st Century Skills: The Challenges Ahead"

105 *Ibid*.

that[106]. What teachers need is much more robust training and support than they receive today, including specific lesson plans that deal with the high cognitive demands and potential classroom management problems of using, for example, student-centred methods[107]. Therefore, changing teaching standards and accountability metrics would not be enough. **Teachers/educators/trainers need to be (re)trained and equipped with the necessary tools and skills**.

Furthermore, it would not be sufficient to invest heavily in the curriculum and human capital without also investing in **assessments** to evaluate what is or is not being accomplished as a result of the study/training. The potential exists today to produce assessments that measure critical skills and are also reliable and comparable between students and educational institutions. However, the efforts to assess these skills are still in their infancy[108].

To conclude, there is a clear need for a better curriculum, better teaching, and better assessments. Efforts to create more formalised **common standards** would help address some of the challenges by focussing efforts in a common direction[109]. Finally, the whole learning ecosystem needs to be kept in mind and the abovementioned advancements need to fit into the overall paradigm of life-long learning.

3.3. Key needs in terms of on-the-job training

The current sub-section addresses the key needs in terms of on-the-job training, and as the name implies, this training would most likely be provided by companies to their employees.

Companies have an important role and responsibility in offering training besides educational institutions themselves. While on-the-job training is an obvious area where companies can get involved in workforce training, they may also explore other ways to participate in joint initiatives with educational institutions for mutual benefit. Some examples of such partnerships can be seen in *Annex B*.

3.3.1. Promoting the notion of life-long learning

KET/AMT specialists need regular retraining and continuous professional development. Skill requirements constantly change due to factors like technological development, globalisation, industrial restructuring, increasing role of ICT and new patterns of work organisation. As a result, employers in many sectors have an increasing need for higher levels of competencies when it comes to technical specialisation, practical and transversal skills[110]. As emphasised above, vocational/tertiary education should be seen a starting base that needs constant advancement throughout the whole career, putting central the notion of **life-long learning**.

Large companies in general agree that **not all competencies can and should be trained by the educational institutions, and that certain specific skills can be better trained "on the job"**. In fact, some large companies prefer to hire individuals with limited experience and to provide them with informal on-the-job training through

106 Based on Rotherham A.J. and Willingham D. (2009) "21st Century Skills: The Challenges Ahead"
107 *Ibid*.
108 *Ibid*.
109 *Ibid*.
110 See CECIMO (2013) The European machine tool industry's Manifesto on skills, September 2013

work in teams and through mentoring by senior colleagues[111]. This preference can be partially explained by a higher level of specialisation needed by large companies when compared to SMEs.

Small companies, in turn, find it difficult to continuously advance the skills of their employees within the life-long learning approach. Firstly, training is a costly activity, and the resources that SMEs can spend on training are typically highly limited in terms of both time and money. Secondly, there is often a lack of organisational capacity within SMEs[112], including human and intellectual resources to provide such training. **Small companies can therefore hardly provide the necessary training themselves, and heavily rely on partnerships with local providers of training and local authorities[113], as well as various supporting structures such as industry associations and cluster organisations**. The latter often imply joining forces and exchanging experiences with other (often competing) companies from the same domain. Companies thus jointly engage in learning activities in order to improve their overall competitiveness, and thus instead of "competing for talent" they "collaborate for talent". Interestingly, SMEs report better skills development outcomes from informal training and skills development activities (particularly through participation in knowledge-intensive service activities) than from formal vocational training[114].

Additionally, **when it comes to retraining of employees from other sectors, certain hesitation from the company's side to do so is reported** (it holds for companies of all sizes), especially if the company has to finance it. Often employment agencies are ready to pay for the training as long as there is a guaranteed job; however, it may take one or more years for somebody to get retrained, and companies in general are reported not to be ready to wait that long[115].

Finally, **the promotion of life-long learning and technological curiosity needs to start already at the very early age**. The exposure of children to technological experimentation, mechanics, programming and other technical and non-technical domains fosters creativity and problem-solving skills, and is crucial for attracting more girls and women into STE(A)M domains. For Europe to gain a competitive edge as an inclusive high-tech society, there is a clear need to cultivate technological intuition and openness already in its youngest citizens of all genders.

3.3.2. Acknowledging change in learning landscape

When addressing the topic of on-the-job training, it is crucial to keep in mind the realities in which **modern learning** occurs, including learners' jobs, habits, behaviours and preferences. An infographic developed by Bersin[116] in 2015 emphasises that today's employees are overwhelmed, distracted and impatient. Flexibility in what, where and how they learn becomes increasingly important. Modern learners want to learn from their peers and managers as much as from experts. They are taking more control over their own development. An estimate was made that 1% of a typical workweek is all that employees have to focus on training and

111 Yawson R. M. (2013) A Systems Approach to Identify Skill Needs for Agrifood Nanotechnology: A Mixed Methods Study, Dissertation, Quinnipiac University - Lender School of Business; University of Minnesota - Twin Cities - Organizational Leadership, Policy, and Development
112 CECIMO (2013) The European machine tool industry's Manifesto on skills, September 2013
113 "Skills Development and Training in SMEs", OECD Skills Studies 2013
114 *Ibid*.
115 From PwC (2016) "Vision Report: Vision for the development of skills for Key Enabling Technologies (KETs) in Europe", developed for DG GROW of the European Commission
116 Bersin by Deloitte (2015) "Meet the modern learner" infographic

development. The abovementioned realities have direct implications for on-the-job training and indicate **the agility of modern learning, decentralisation of training activities and a growing importance of informal learning**.

The learning landscape today thus looks completely different than it did five years ago. Modern learners expect content (and the learning approach overall) to be short and personalised and are more committed to their learning goals[117]. These trends indicate the need for change for both content and technology in the learning space. The need now exists for learning solution providers to visualise what has not been seen before and formulate **solutions that blend modern learning with traditional and personalised learning experiences** and bring these at par with contemporary mobile applications and just-in-time learning methods[118].

The technology-enabled learning trends that will have a significant impact on the workplace learning ecosystem include the following[119].

Need for microlearning

Learners expect content that is consistent with the new format of digital learning, namely short, relevant, contextualised, personalised, on their mobile devices. While most learning leaders identify with this trend, not many of them actually apply microlearning. That is because microlearning solutions require design and technology, which most existing platforms, authoring tools, and processes do not fully support. **Most organisations today are dealing with challenges in technology infrastructure and established design best practices that prevent them from adopting microlearning quickly**[120].

Microlearning goes beyond content, and makes it possible to learn on-the-go in small specific bursts. To this end, microlearning offers small businesses an opportunity to approach employee training in a whole new way[121]. However, small companies may need support with exploring the available microlearning programs and strategies.

However, microlearning should not be viewed as a replacement of more extensive forms of learning, when it comes to educating/training **experts** and obtaining the 'big picture' of a certain topic. It is rather meant for complementing the more traditional forms of learning, and offers an efficient way of advancing existing skill-base.

Need for mobility in learning

Mobile learning or m-learning also suggests to be a suitable option for SMEs. Most people have access to at least a smartphone, and people often have multiple mobile devices. With an audience supplying their own hardware, the cost of implementing m-learning programs becomes more affordable than other alternatives. Furthermore, m-

117 Basu S. (2017) "5 Technology-Enabled Learning Trends In 2017", published in eLearning Industry on 15 February 2017

118 *Ibid.*

119 This section has been developed based on the analysis conducted by PwC in the context of a parallel initiative on "Promoting Online Training opportunities among the workforce in Europe" (contract nr. EASME/COSME/2017/001), for EASME/DG GROW of the European Commission.

120 Basu S. (2017) "5 Technology-Enabled Learning Trends In 2017", published in eLearning Industry on 15 February 2017

121 Emerson M. (2015) "How to Handle Employee Training in Your Small Business", published on 10 November 2015

learning also allows employees to feel an extra level of responsibility for their training, since their training modules are literally always in their hands[122].

There is a common misconception that m-learning is only relevant for large companies. However, "the mobile app revolution" is suggested to have an especially powerful impact on small businesses, as it helps these companies reduce expensive, redundant processes and makes them leaner and more cost-efficient. Some apps offer free versions to small business owners to help them better train their employees[123].

Need for the connection with the "real world"

Apart from making learning engaging, there is a need to bring learners closer to the "real world". Immersive and interactive technologies like Virtual/Augmented Reality (VR/AR), as it has the ability to close infrastructure gaps, will have an increasing impact on how organisations can achieve that[124]. Some companies are now using VR/AR technologies to increase sales effectiveness, educate customers, and establish brand recall. Different VR/AR cases and requirements are expected to emerge over several other areas in the coming years[125].

Small businesses can now also leverage on VR/AR solutions to advance experiences of their customers. Due to the initially high cost of the relevant equipment, these technologies were not always affordable to SMEs. However, as the technologies become more mature, the cost of the equipment will continue dropping further[126].

Need to make learning engaging

Gamification has proved to be an effective strategy for employee engagement[127]. A vast majority of learning teams use gamification as a component of their digital learning strategy. The use of gamification in learning solutions is expected to grow in the coming years[128].

While many of the companies adopting gamification are large enterprises, it is also suitable for small businesses and startups. Gamification has a good fit with the unique office culture of startups[129]. One of the main reasons why small businesses hesitate to explore gamification is the fear that these systems will be expensive, and difficult to introduce. However, the gamification market is becoming more specialised every day, leading to more affordable "turn-key" gamification solutions that are also feasible for SMEs[130].

Besides gamification, learning can be made more engaging through the facilitation of social learning and personalisation. These aspects are addressed below.

122 Balls A. (2017) "Why Use Mobile Learning for a Multigenerational Workforce", published on AllenComm on 30 November 2017
123 *Ibid*.
124 Basu S. (2017) "5 Technology-Enabled Learning Trends In 2017", published in eLearning Industry on 15 February 2017
125 *Ibid*.
126 My Smart Gadget (2016) "Virtual reality for small business", published on 16 September 2016
127 Richardson A. (2017) "Gamification: A Valuable Employee Engagement Strategy", Aspire Blog, 13 February 2017
128 *Ibid*.
129 Watson Z. (2014) "5 Gamification Companies for Small Businesses", published on Technology Advice on 26 March 2014
130 *Ibid*.

Need to facilitate social learning

Collaboration is becoming a mainstream tool to engage employees, enable for smarter decision-making and enhanced business outcomes. Collaborative networks are shortening the time-to-business and cutting costs to drive employee engagement and transparency. **Social learning** has a clear role to play as learning teams build and deploy the modern learning technology in the organisation[131].

If a company has an online forum board where learners post their questions or concerns, an effective strategy could be to move that over to a **social media platform** where they can engage in a more lively and educational discussion with their peers. It is also possible to bring discussions to blogs, and virtual meeting sites. If there are certain topics that seems to be actively discussed amongst the learners, it would be advisable to make that a feed or post on a dedicated social media page[132].

Need for the personalisation of learning

The digital learning field is moving into the direction of creating "**Learning Engagement Systems**", i.e. solutions that use profile data about learners, their personalities, their habits, goals and feedback from others. The objective is to drive personalised learning and provide coaching and connections to help keep workers connected with their ambitions and their personal development priorities (enabled by AI)[133].

Specifically, a distinction needs to be emphasised between **personalised and personal learning**. While personalised learning implies some degree of customisation, essentially all learners get the same experience. In case of personal learning, the role of the training system is not to provide, but to *support* learning, while the decisions about what to learn, how to learn, and where to learn are made outside the training system, by the individual learners themselves[134]. Personalised learning can be compared to choosing from a menu at a restaurant, while personal learning is comparable to shopping at a grocery store and cooking your own meal[135]. The notion of personal learning builds on the idea that if people are to become effective learners, they need to be able to learn on their own[136]. For that, they need to be able to find the resources they need, assemble their own curriculum, and follow their own learning path. In this case, education/training providers and policy makers can only facilitate this process, while keeping in mind that there are too many and too varied needs of individual learners.

The needs presented in this chapter will be taken into account when developing the curriculum guidelines and recommendations for specific support measures. The current outcome of this exercise is presented in Chapter 5 of this report.

131 Basu S. (2017) "5 Technology-Enabled Learning Trends In 2017", published in eLearning Industry on 15 February 2017
132 Pappas C. (2014) "8 Top Tips to Create an Effective Social Learning Strategy", published in eLearning Industry on 28 July 2014
133 Fosway Group (2017) "Digital Learning Realities 2017: Part 1 -Organisation, Headcount, Budget and Investment", in association with learning technologies, May 2017
134 Downes S. (2016) "Personal and Personalized Learning", 17 February 2016
135 *Ibid*.
136 *Ibid*.

4. STATE-OF-PLAY ANALYSIS

The current chapter presents a state-of-play analysis with regard to supply and demand of AMT professionals in Europe, the key players in AMT education and training in Europe, as well as the relevant policy initiatives and key publications. This chapter also contains sample descriptions of good practice curricula and an overview of the key barriers and solutions with regard to AMT-related education and training in Europe.

4.1. Supply and demand analysis

Getting and keeping as many people at high productivity levels is an excellent way of maximising **welfare**. Welfare here is meant in the economic sense, and refers to the sum of producer and consumer surplus. Staying as close as possible to the moving productivity frontier with the working population is the best hope of achieving the Lisbon objectives of competitiveness, innovation and long-term growth.

The best way, in turn, to optimise productivity is **adequate education**. What is adequate in the era of rapid technological change is subject of intense discussions, as not just the range of jobs will change over time, but the spectrum of competencies itself needed for the majority of jobs will change. Adequate education has to transform from the orthodox classroom-until-20 system to a system of lifelong learning and upskilling.

There is in theory a massive **demand** for lifelong learning and upskilling. However, the demand is latent, and there is no up-to-scale provision system in place. Given the economic imperative of adequate education, there is a clear need for a market for lifelong learning and upskilling. In fact, developing such a system is arguably one of the most important challenges of the EU.

Economic theory suggests that there are at least four types of **stakeholders** that will benefit from the system, and that each have a role to play:

(1) Being adequately educated is, first of all, relevant for the individual herself. It raises the ability to participate in the economic process, contributes to the sense of inclusion, and enhances the potential to earn the means of living. Being and staying adequately trained is therefore a private responsibility, at least to a certain extent. The decision to invest in education is a trade-off between the material and immaterial costs associated with the training programmes and the expected material and immaterial returns.

(2) Having a well-educated workforce is crucial for companies and institutions in order to stay ahead of the curve in the market place. Again, this motivates the responsibility of the employer to invest, and again, the decision to invest is a cost-benefit analysis.

(3) It is good for society if we are all adequately educated. My adequate education adds to higher growth, of which society as a whole benefits. This so-called externality of learning is the first of two important economic arguments for the State to take a certain responsibility.

(4) The fourth stakeholder obviously is the teaching industry, both private and public, as there are business cases to be made out of the developing demand.

A well-functioning lifelong learning and upskilling market does not come into existence automatically, due to a number of so-called **market failures**. Among them are:

- **Myopism** - individuals tend to undervalue long-term benefits of education in their trade-off against short-term investment in time, effort and money;
- **Sub-scale** - provision is scattered and fragmented, and therefore far more costly than necessary. A learning and up-scaling curve needs to be paid somehow by someone;
- **Intransparency** - companies and institutions, especially the smaller ones, face huge search costs in finding the right programmes for their specific needs;
- **Incentive structures** - currently, the funding structures of the orthodox public teaching industry are not designed to incentivise the development of the system with the specific requirements for the future.

These market failures constitute the second reason for intervention by the State, and especially at the EU level.

The current sub-section describes the situation in the labour market regarding AMT-related skills, addresses key trends and makes estimates for supply and demand of labour with AMT-related skills for Europe for the coming years.

The employed definition of AMT stems from the definition by the European Task Force for Advanced Manufacturing[137]. Advanced manufacturing is considered to encompass all production activities applying cutting-edge knowledge and/or non-technological innovation leading to improvements of existing products, processes and business models and to the production and diffusion of new ones[138]. The employed definition is thus of broad nature.

The analysis is based on the following methodological considerations:

- The most recent available data refers to 2017. Vacancy rates are only available for most European countries as of 2012. The estimates of the future supply and demand for AMT-related labour refer to 2026, following the availability of data in employment growth forecasts.
- Europe is in this analysis considered to be the European Union and its Member States.
- To define manufacturing, the Eurostat's Statistical classification of economic activities (NACE Rev. 2[139]) was used. The manufacturing sector

137 https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/link/european-task-force-advanced-manufacturing
138 *Ibid*.
139 NACE Rev. 2: Statistical classification of the economic activities in the European Community, Eurostat (2008), ISBN 978-92-79-04741-1

is specifically defined as the economic activities belonging to the section 'C Manufacturing' in the NACE classification, including all the 24 sub-sections[140]. This definition is equal to the one used by Cedefop in their skills forecasts[141].

- For estimates on occupational level, the International Standard Classification of Occupations (ISCO08) was used, which is also employed by Eurostat and Cedefop.
- The requirement for AMT-related skills has been attributed to the following five occupations in manufacturing: Managers, Professionals, Technicians and associate professionals, Craft and related trade workers and Plant and machine operators[142].
- In order to accurately estimate the demand and supply of labour, the use of FTE would be preferred. However, following the availability of the data, this analysis looks at the absolute number of professionals, which is also the approach used by Cedefop in their Skills forecast.

In the remainder of this sub-section, the current and the future demand and supply for AMT-related skilled labour in manufacturing is examined. The two are then combined to explore AMT-related labour market balance.

4.1.1. Estimation of AMT-related labour demand in manufacturing

Below, the estimation of both the current and the future AMT-related labour demand in manufacturing in Europe is addressed. As emphasised above, a broad definition of AMT is used.

Estimation of current AMT-related labour demand in manufacturing

The current AMT-related labour demand consists of two components:

(1) The current employment of AMT-related skilled labour;

(2) Vacant positions in manufacturing.

Eurostat provides historical statistics on employment data in manufacturing on occupational and country level, which was used here to obtain data for the first component of labour demand[143].

140 The subsections are: Manufacture of food products; beverages; tobacco products; textiles; wearing apparel; leather and related products; wood and of products of wood and cork, except furniture; paper and paper products; coke and refined petroleum products; chemicals and chemical products; basic pharmaceutical products and pharmaceutical preparations; rubber and plastic products; other non-metallic mineral products; basic metals; fabricated metal products, except machinery and equipment; computer, electronic and optical products; electrical equipment; machinery and equipment; motor vehicles, trailers and semi-trailers; other transport equipment; furniture; other manufacturing and repair and installation of machinery and equipment.

141 Skills supply and demand in Europe: Methodological framework, Cedefop (2012)

142 This leaves out the following occupations: Clerical support workers, Service and sales workers, Skilled agricultural, forestry and fishery workers, Elementary occupations; as well as Armed forces occupation and the statistical variable No response.

143 Eurostat statistics 'lfsa_eegan2'

As there are no historical statistics of the number of vacant positions, it was calculated through the use of manufacturing vacancy rates[144] and the current employment of AMT skilled labour in manufacturing, according to the formula below:

$$Vacant\ positions = Employment * \frac{Vacancy\ rate}{1 - Vacancy\ rate}$$

However, for France, Italy and Malta no vacancy rates are available in the Eurostat statistics. For these countries, the arithmetic mean of vacancy rates was used in the remaining European countries in the calculation.

As there are no available statistics on vacancy rates on occupational level, an assumption was made that the vacancy rates in each occupation equal the overall vacancy rates. This is a rough assumption, as vacancy rates are likely to be higher in some occupations than others, but it was necessary to calculate AMT-related skilled labour demand. At the same time, as vacant positions in the overall economy represent a small share of labour demand, the assumption should not distort the estimations in a significant way.

The sum of employment of skilled labour and vacant positions in the AMT-related occupations yields the historical and current AMT-related labour demand in the Europe.

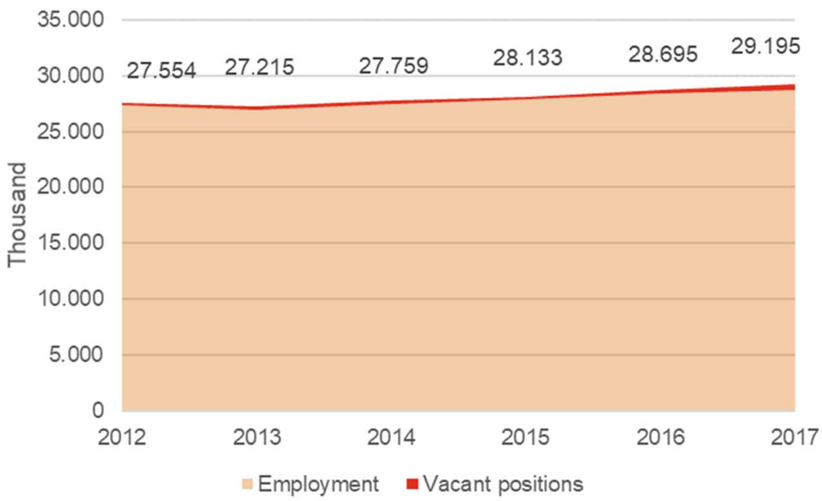


FIGURE 4-1: European AMT-related labour demand (in thousands)

AMT-related skilled labour demand is estimated at 29,2 million in 2017. As is shown in Figure 4-1, the related employment represents 28,7 million in 2017, and constitutes the larger share of AMT-related labour demand.

The demand for AMT-related skilled labour is significant in several European national economies. The largest calculated demand of AMT-related skilled labour can be found in Germany (6,1 million), Italy (3,5 million), Poland (3,0 million), France (2,9 million) and the United Kingdom (2,4 million). In terms of relative figures, the calculated AMT-related employment constitutes the largest share of the active population in Czech Republic (23,6%), Slovenia (20,6%), Slovakia (19,5%) and Hungary (19%).

144 Eurostat statistics 'jvs_a_rate_r2'

Estimation of future AMT-related labour demand in manufacturing

To estimate the future demand for AMT-related skilled labour, the Cedefop's forecasts for annual employment growth rates were used for each of the relevant AMT-related occupations in manufacturing over the period 2018 to 2026[145][146].

As long as there is unemployment in the economy, vacant positions signify the presence of a skills gap, but also of other market frictions. An assumption was made that the vacant positions will grow at the same rate as employment, and consequently that there is no reduction in the skills gap. If the skills gap in reality will be decreasing, then this analysis is overestimating the AMT-related labour demand. However, as the number of vacant positions is small, compared to the total AMT-related labour demand, the impact of overestimation is limited.

There is a large variation in the forecasted employment growth rates for the AMT-related occupations. The figures below show the forecasted annual employment growth rates for each AMT-related occupation in the period 2018 to 2026. A first observation is that forecasted employment growth overall varies largely between countries, ranging from an expected growth of 3,3% in Luxembourg to an expected decrease of -0,8% in Lithuania. However, for most countries, growth is forecasted in the occupations 'Managers', 'Professionals' and 'Technicians', with an expected decrease of employment of 'Craft workers'.

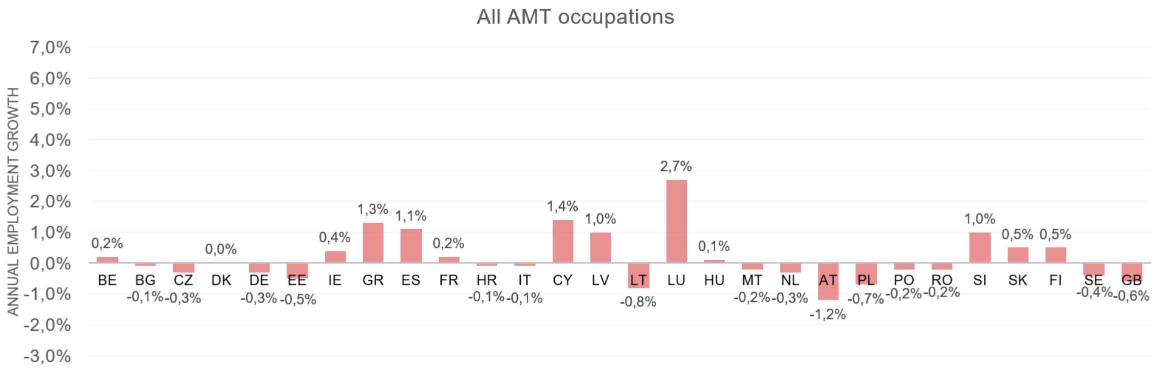


FIGURE 4-2: Annual employment growth for AMT-related occupations in Europe 2018-2026

145 http://www.cedefop.europa.eu/en/publications-and-resources/data-visualisations/skills-forecast
146 See also Skills supply and demand in Europe: Methodological framework, Cedefop (2012) for methodology on estimation of employment growth

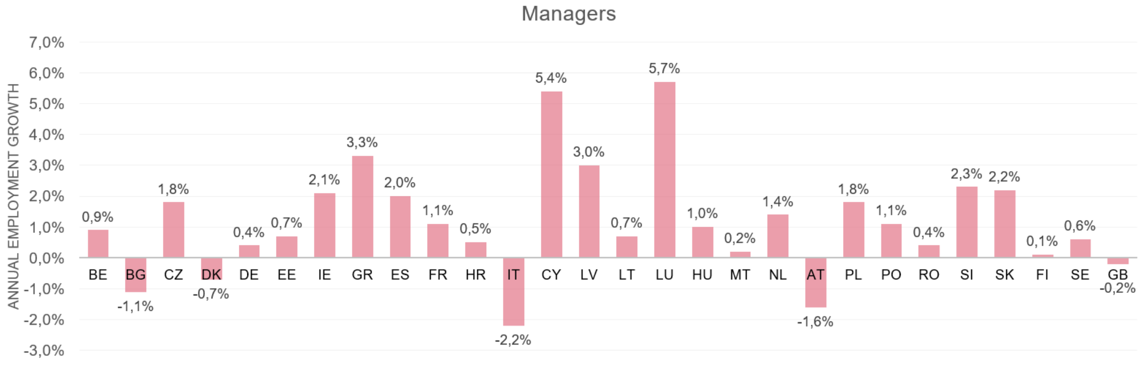


Figure 4-3: Annual employment growth for AMT-related Managers in Europe 2018-2026

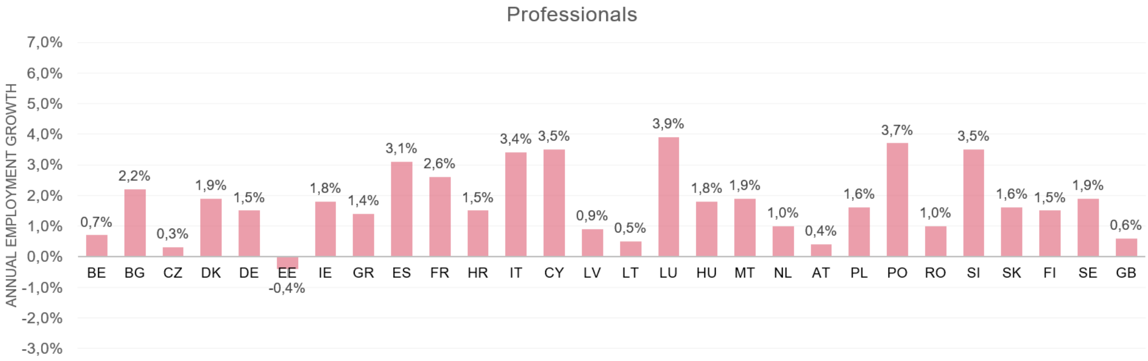


Figure 4-4: Annual employment growth for AMT-related Professionals in Europe 2018-2026

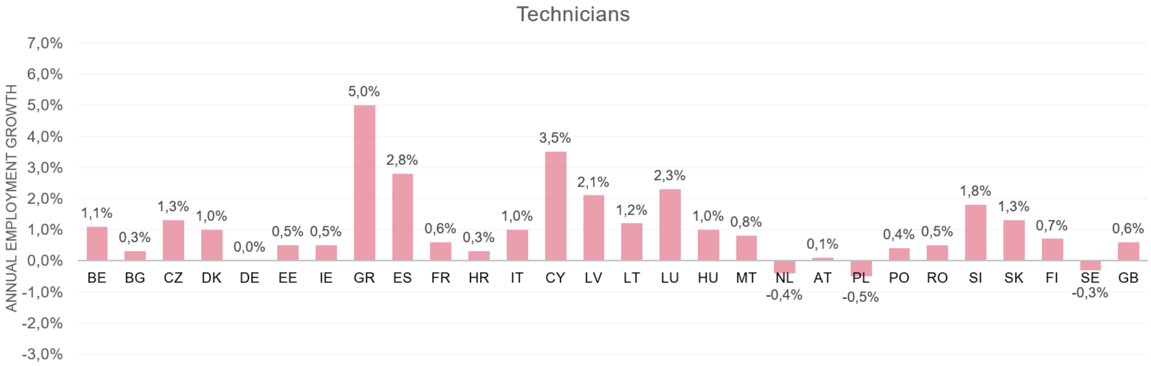


Figure 4-5: Annual employment growth for AMT-related Technicians in Europe 2018-2026

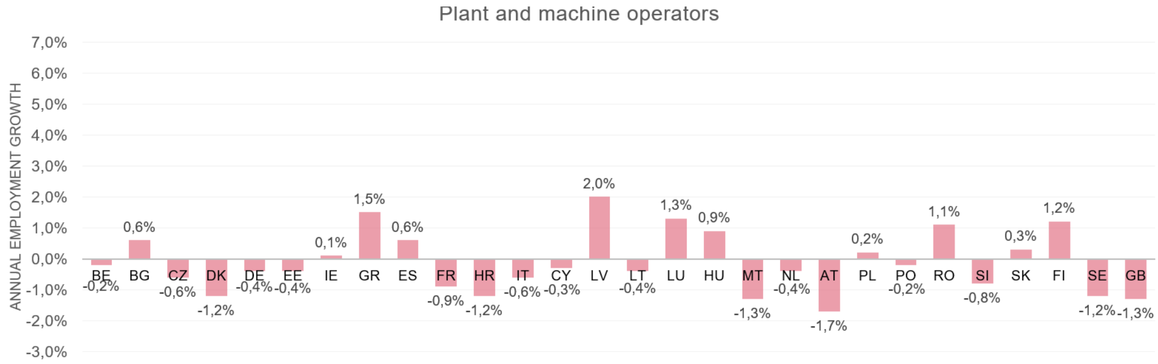


Figure 4-6: Annual employment growth for AMT-related Plant and machine operators in Europe 2018-2026

Cedefop forecasts a stagnation of the AMT-related employment growth. For the European Union, Cedefop forecasts an overall annual decline in employment of AMT-related skilled labour of 0,1%. It is important to point out that there are considerable differences in forecasts for different skill levels (namely, low- medium- and highly skilled workers, with the first two categories forecasted to decline, and the third one – to grow). On occupational level, the decline is expected particularly among craft workers, while growth is expected for managers, professionals and technicians. Overall, the AMT-related labour demand in Europe is expected to fall by more than 300 000 employees by 2026, as seen in Figure 4-7.

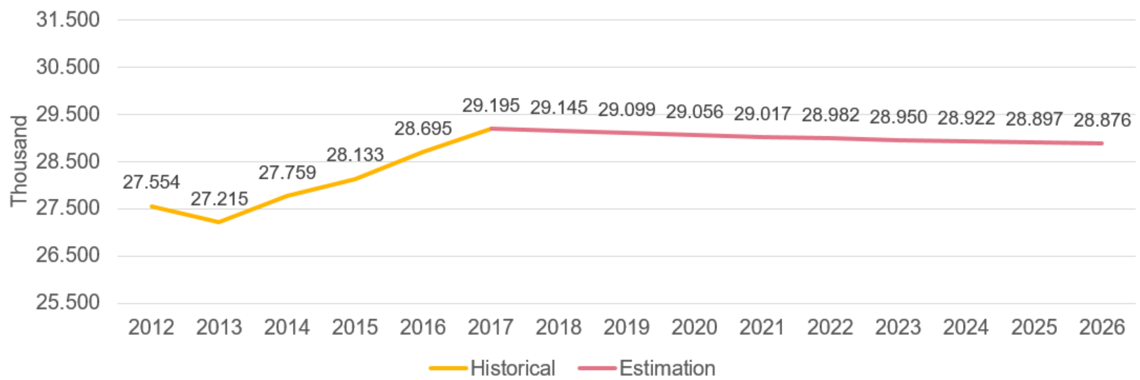


FIGURE 4-7: Estimation of AMT-related labour demand in Europe (in thousands)

4.1.2. Estimation of labour supply in manufacturing

Below, the estimation of both the current and the future AMT –related labour supply in Europe is addressed.

Estimation of current AMT-related labour supply

The current supply of AMT-related skilled labour consists of three components:

- AMT-related skilled labour that is currently employed in manufacturing;
- AMT-related skilled labour that is currently unemployed;
- AMT-related skilled labour that is currently employed outside the manufacturing domain.

The first component is the same as the employment described in section 4.1.1., and it is not replicated here.

Due to lack of statistical data on unemployment specifically among AMT-related labour or in manufacturing generally, the second component has been estimated using Eurostat statistics on the overall unemployment rate in the economy for each Member State[147]. An assumption was made that the unemployment rate in each of the AMT occupations equals that of the overall economy. The formula below was used to calculate the number of unemployed in AMT-related occupations.

$$Unemployment = Employment * \frac{Unemployment\ rate}{1 - Unemployment\ rate}$$

As no statistical data (or comparable equivalents) are available for the third component, it was left out of the estimation of the AMT-related labour supply. The AMT-related skilled labour that is currently employed outside the AMT domain was thus not included.

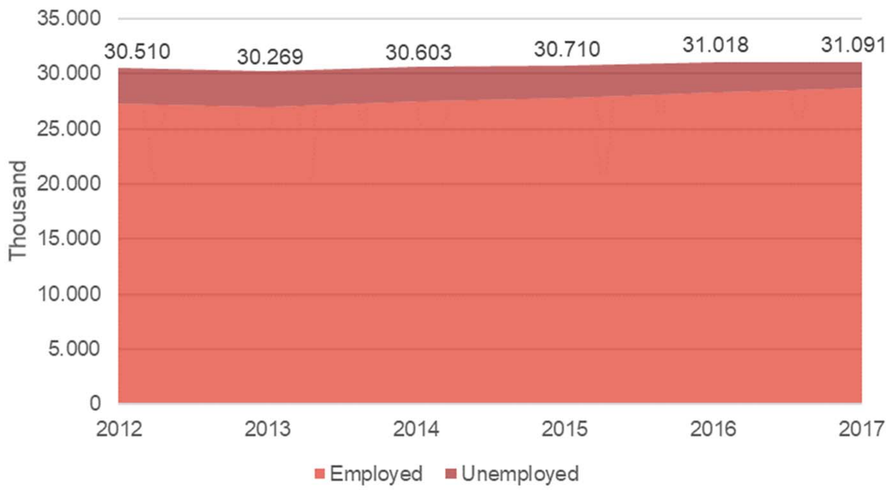


FIGURE 4-8: European supply of AMT-related skilled labour (in thousands)

The European AMT-related skilled labour supply is estimated at 31,1 million in 2017, and over the period 2012 to 2017, the supply is estimated to have grown by 1,9%. The unemployed AMT-related labour constitutes about 7,6% of the total European AMT-related labour supply, and follows the decline in national unemployment following the years after the financial and debt crisis.

Estimation of future labour supply in manufacturing

To estimate the first component of future labour supply, the employment growth forecasts of Cedefop were also applied. For the estimation of future unemployed AMT-related skilled labour, an assumption was made that the unemployment will grow with the same rate as AMT-related employment, and consequently that the unemployed AMT-related labour as share of AMT-related labour supply remains constant.

Change in unemployment is likely to be influenced by three main drivers, namely unemployed workers being employed, new entrants to the labour market (e.g. newly educated workers) and workers leaving the labour market. The first driver will have

147 Eurostat statistics 'une_rt_a'

no consequences for the estimation of AMT-related labour supply. This follows from the reasoning that the employment of an unemployed AMT-related worker, simply moves that person from the second to the first component of AMT labour supply, while the supply itself remains unchanged. The second and the third drivers might result in over- or underestimation of unemployment, and consequently labour supply, in this analysis.

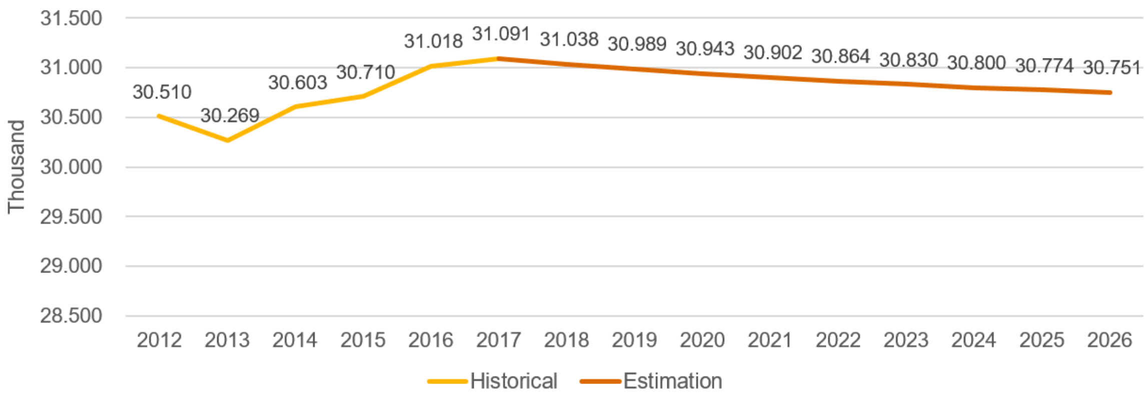


FIGURE 4-9: Estimation of AMT-related labour supply in Europe (in thousands)

As can be seen from the Figure, the AMT-related labour supply in Europe is expected to be declining in the coming years, with a projected difference of 340 000 by 2026.

4.1.3. Combining estimations of AMT-related skilled labour supply and demand

Factors that create the unbalance in the AMT-related labour market refer to the unemployment and the vacant positions. In a labour market with unemployment, vacant positions can be a sign of skills gap and other market frictions, where available labour does not meet the requirements of employers. These requirements can be connected, among others, to skills, education, occupational level and location.

According to the estimation, there is, and will continue to be, sufficient overall AMT-related labour supply to satisfy the demand from AMT-related employers in Europe. However, there are likely to be large differences between countries and between different AMT-related occupations. The analysis thus suggests that there are enough workers in AMT, but they do not always have the education and/or skills required by employers, or that excess demand and/or supply of AMT labour differs per Member State.

Excess labour supply is the difference between labour supply and labour demand. A positive excess labour supply indicates that there is more than enough labour supply in the market to satisfy the labour demand of the economy, while the opposite holds true for a negative excess labour supply. In Figure 4-10, one can observe that there is an estimated excess of overall AMT-related labour supply for all Member States, except for Czech Republic.

TABLE 4-1: European AMT-related labour market in 2017, 2021, 2026 and 2030 (in thousands)

	2017	2021	2026	2030
Supply	**31.091**	**30.957**	**30.751**	**30.689**
Employment	28.728	28.613	28.414	28.357
Unemployment	2.363	2.344	2.337	2.332
Demand	**29.195**	**29.077**	**28.876**	**28.818**
Employment	28.728	28.613	28.414	28.357
Vacant positions	467	463	462	461
Excess labour supply	**1.896**	**1.881**	**1.875**	**1.871**
Market unbalance	**467**	**463**	**462**	**461**

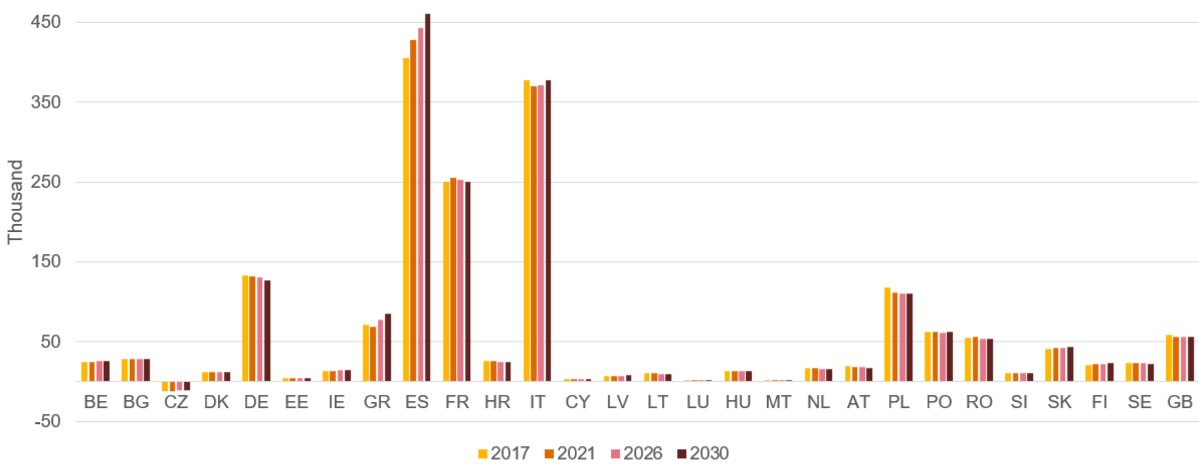


FIGURE 4-10: Excess AMT-related labour supply in 2017, 2021, 2026 and 2030 in specific Member States (in thousands)

While the analysis suggests that there is mostly enough AMT-related labour supply to satisfy the labour market overall, the differences need to be explored at the level of specific AMT-related occupations. *Annex E* analyses the AMT-related labour supply for each AMT-related occupation in each Member State.

4.2. Key players in AMT education and training in Europe

The analysis within this sub-section will be presented separately for HE, VET and on-the-job training. In general, we were not able to identify studies that would offer a comprehensive analysis of the AMT-related education and training offer in Europe. The information presented below represents a synthesis of findings coming from fragmented desk-research sources and complemented by in-depth interviews and expert workshops.

It is important to point out that critical career decisions are being made already more than a decade before a student enters the workforce. For example, secondary school students often have to make the decision to take appropriate math and science courses that will prepare them for higher education in science & engineering fields about fourteen years before they start working[148]. Consequently, at this point, children already need to be familiar with the development opportunities within AMT. The promotion of AMT-related education and careers and the application of the relevant models and approaches should therefore start early in the educational process.

4.2.1. Higher Education

When analysing the AMT-related HE offer in Europe, it is important to keep in mind that AMT professionals do not necessarily have to follow an explicit AMT-focussed educational trajectory. Skills required for AMT heavily rely on a more general skill set of STEM domains (such as Computer Science, Engineering, Mathematics, Chemistry, Physics etc.), but also on a broad range of non-technical competencies (such as Project Management, Law, Economics etc.).

In the context of the current initiative, we suggest adopting a more narrow perspective and **examining explicitly AMT-oriented educational offer in Europe**, in order to keep the analysis focussed and manageable. From this perspective, the focus needs to be put on the educational programmes related to Manufacturing Engineering and similar domains. Specialisation includes robotics and automation, production systems, engineering design and advanced materials. Manufacturing Engineering focusses on the research, design and development of manufacturing systems, processes, machines, tools and equipment[149]. While Bachelor programmes often have a more generic orientation, Masters in Manufacturing Engineering provide students with a detailed understanding of each level of the manufacturing process, combining skills in mathematics, science and business to develop innovative ways of designing systems and processes[150].

In order to analyse the quality of the Manufacturing Engineering offer in Europe, we used the **QS World University Rankings by Subject 2018[151]** (the overall ranking is based on four indicators, namely academic reputation, employer reputation, citations per paper and h-index citations[152]). The ranking is available per subject at the level of Engineering and Technology sub-domains. For AMT, we selected a filter "Engineering - Mechanical, Aeronautical & Manufacturing" (top ranking university per country). Although the ranking is not explicitly focussed on AMT, it can still be a good proxy of the quality of relevant education at specific universities, and allows to examine Europe's position against that of other world regions.

The results of the abovementioned filtering exercise suggest that within the **top 10 world's universities in the field of "Engineering - Mechanical, Aeronautical & Manufacturing"**, **only three come from Europe** (and all three are from the United

148 http://www.nanokids.rice.edu/emplibrary/NanoKids_Presentation_English.pdf cited in PwC (2013) "Comparison of European and non-European regional clusters in KETs: The case of semiconductors", a study for DG CONNECT

149 https://www.topuniversities.com/courses/engineering-manufacturing-production/grad/guide#tab=0

150 *Ibid*.

151 https://www.topuniversities.com/subject-rankings/2018

152 https://www.topuniversities.com/university-rankings/university-subject-rankings/2015/materials-sciences

Kingdom[153]). The majority of universities in this top 10 come from the United States[154], and one university is located in Japan[155]. Based on the abovementioned numbers, **Europe currently does not hold a leading position with regard to the quality of the AMT-related HE offer in the world,** although it is still a home base for some of the top universities in this field. When performing a similar exercise for the top 20 universities, the share of European universities remains the same, with 6 out of 20 coming from Europe (7 come from East Asia and the remaining 7 come from the Unites States). It is important to point out a prominent role of East Asian universities in the top 20.

Similarly, the World University Rankings (WUR) in Engineering and Technology of 2018[156] provides a ranking of the 500 best institutions within the field of manufacturing and mechanical engineering. While the database is not an exhaustive overview of the relevant European HEIs, it still provides some indication of the supply, as presented in Figure 4-11.

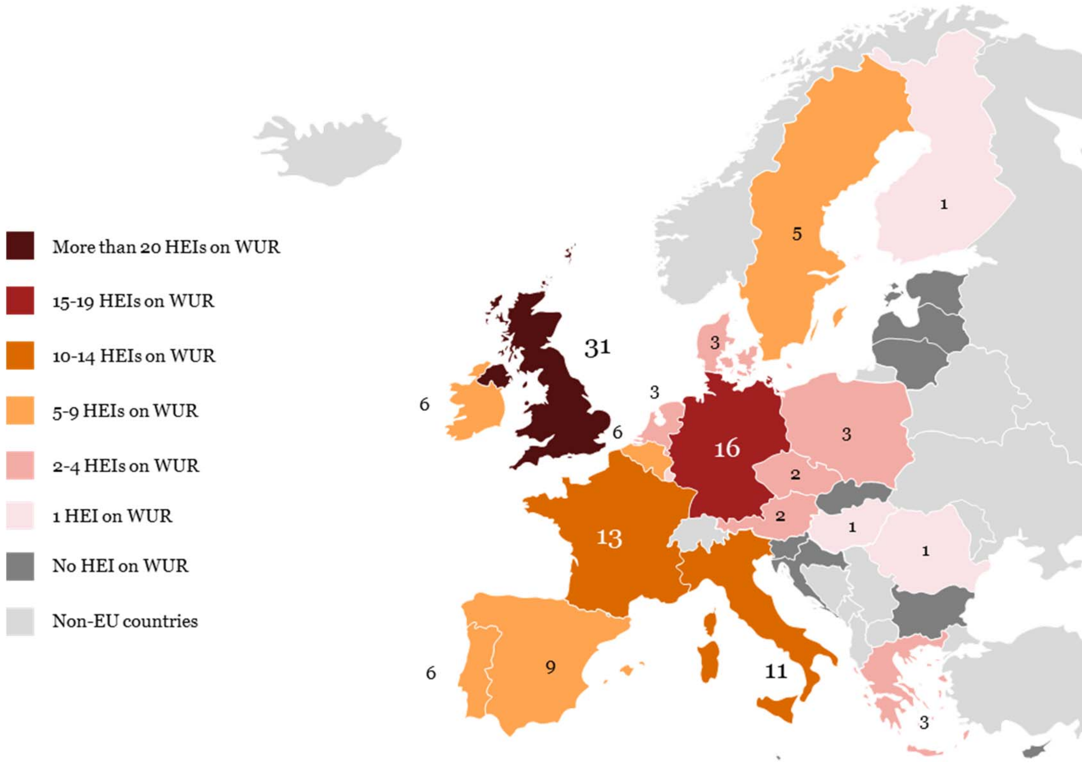


Figure 4-11: Overview of European HEIs within Manufacturing and Mechanical Engineering[157] (the list is not exhaustive)

153 Those include University of Cambridge, University of Oxford and Imperial College London.
154 Those include Massachusetts Institute of Technology (MIT), Stanford University, Harvard University, University of California Berkeley (UCB), University of Michigan and Georgia Institute of Technology.
155 Namely the University of Tokyo
156 https://www.timeshighereducation.com/world-university-rankings/2018/subject-ranking/engineering-and-IT
157 Based on the data from the World University Rankings: https://www.timeshighereducation.com/world-university-rankings/2018/subject-ranking/engineering-and-IT#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/stats

The Figure indicates large differences between the EU Member States. The five countries with the highest number of relevant institutions (based on WUR data) include the United Kingdom, Germany, France, Italy, and Spain, and combined represent more than 70% of the relevant HEIs. Also in terms of the reviewed quality of the institutions, there are significant differences between the countries, with the highest ranked institutions located in the United Kingdom, Netherlands, Germany, Belgium and Sweden.

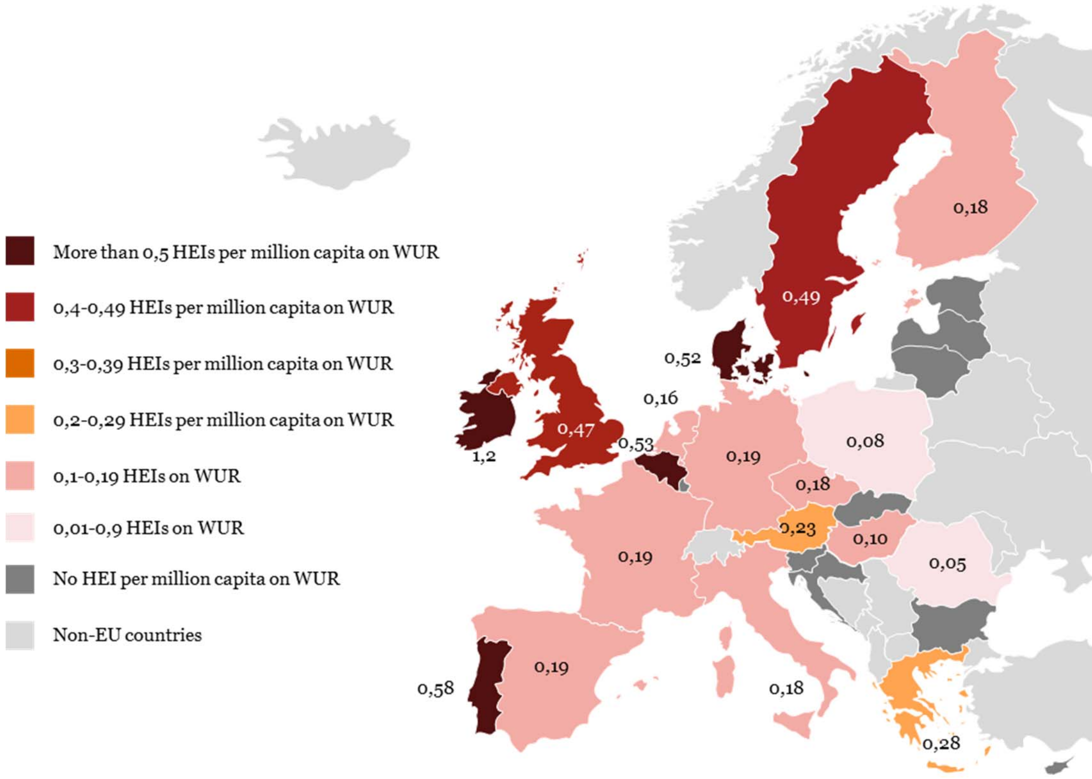


Figure 4-12: Overview of European HEIs per million capita within Manufacturing and Mechanical Engineering[158,159] (the list is not exhaustive)

Figure 4-12 presents the number of HEIs per million capita. This approach demonstrates the size of the educational offer in proportion to the total population of specific counties. As can be seen from the Figure, countries that have the highest number of HEIs within Manufacturing and Mechanical Engineering domain per capita include Denmark, Ireland, Belgium and Portugal. However, it is important to point out that the size of the institutions is not considered here.

The approach of deriving good practice examples based on university ranking is fact-based and thus defendable. At the same time, it relies on past performance of universities and tends to be skewed towards well-established prominent educational institutions. It is therefore likely to overlook emerging and highly promising good practice examples from new and/or less renowned institutions. To this end, we complemented the results of the abovementioned analysis with an alternative

158 Based on the data from the World University Rankings: https://www.timeshighereducation.com/world-university-rankings/2018/subject-ranking/engineering-and-IT#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/stats
159 Population data from Eurostat. Note that for Poland population data was only available for 2017Q4

approach. The latter implied a broad stakeholder consultation, supported by desk-research, and extraction of good practices that promise to become highly impactful in the near future. Annex B of this report contains illustrative examples of such new/alternative models for education and training in KETs and AMT.

Using search engines specialised in available study programs, we developed *illustrative* descriptions for some European countries. The following study portals have been used: *Top Universities*[160], *FindAPhD*[161] and the bachelors, masters and PhD portal *Bachelors portal*, *Masters portal* and PhD portal provided by Study Portal[162]. These three Member States (namely Finland, United Kingdom and Lithuania) were chosen in an arbitrary way, based on the availability of data, with an objective to illustrate the situation in different parts of the EU. We were not able to identify studies that would provide similar type of analysis for all EU Member States.

AMT-related HE in Finland

Finland has several HEIs providing AMT-related Bachelor degrees, such as Tampere University of Technology and Häme University of Applied Sciences. The study programmes provide a solid foundation for understanding AMT, but offer limited specialisation. In-depth knowledge thus requires continued studies. However, there is a large supply of different Master degrees, with more than 100 listed in the Study portal. These programmes give specialisation within subjects such as Factory Automation and Robotics, Autonomous Systems, Advanced Structural Design and Robotized Welding. The number of PhD-programmes within AMT is limited to a few providers. For example, Tampere University of Technology offers PhDs within the focus areas of Automation Science, Mechanical and Production Engineering and Materials Science.

AMT-related HE in the United Kingdom

The United Kingdom has a large supply of HEIs offering Bachelor degrees within engineering in general and manufacturing in particular. According to the Top University and Study portal databases, there are 78 relevant HEIs and nearly 1,300 Bachelor study programmes. Several of these universities are also ranked amongst the world's leading universities in the domain. British Bachelor programmes represent a combination of general degrees and degrees providing specialisation within AMT, such as Mechanical Systems Engineering and Robotics and Artificial Intelligence. There is also a large supply of Master study and PhD-programmes, offering both the general degrees in mechanical engineering, but also specialisations in AMT[163], robotics and advanced materials engineering.

AMT-related HE in Lithuania

In Lithuania, there are only a few providers of HE relevant to AMT, the two primary being Kaunas University of Technology and Vilnius Gediminas Technical University[164]. The Bachelor programmes offer a fairly high level of specialisation, with programmes

160 Global database of 4,820 HEIs, https://www.topuniversities.com/universities
161 Approximately 4,000 PhDs in the selected countries, https://www.findaphd.com/
162 Global database of 79,793 bachelors, 59,793 masters and 4,018 PhD's, https://www.studyportals.com/press-releases/about-studyportals-general-information/
163 https://www.port.ac.uk/study/courses/msc-advanced-manufacturing-technology
164 https://www.vgtu.lt/studies/study-programmes/undergraduate-studies/294829

in the domains of material physics, mechatronics and robotics. The PhD-community appears to be small with just a few relevant PhD-programmes and researchers.

The Highlight below offers some more illustrative examples of relevant HEIs in Europe, collected though expert workshops.

Highlight 4-1: Illustrative examples of AMT-related educational offer in Europe[165]

Initiative name: Aalto Design Factory[166]

Institution: Aalto University

Country: Finland

What: Experimental learning and multidisciplinary knowledge

Description: Aalto Design Factory (ADF) was born from a research project focussed on creating an ideal physical and mental working environment for product developers and researchers. Today ADF is one of the spearhead projects and one of the first physical manifestations of Aalto University encouraging and enabling fruitful interaction between students, researchers, and professional practitioners.

Originating from product development and design education, Design Factory provides an environment that is suitable for experiential learning. The Design Factory approach combines disciplinary knowledge with design thinking and working life skills, such as collaborative working style, effective communication skills, and ability to implement theory to practice.

Elements of learning in ADF include having teacher as a facilitator and student as an active knowledge creator; information gathering and evaluation of various possible solutions; visualising, prototyping and experimenting with ideas; having a real-life problem as a basis for learning; interdisciplinary group work, and reflection.

Initiative name: Roboterfabriek[167]

Institution: Technical University of Munich

Country: Germany

What: Holistic robotics education

Description: The major goals of roboterfabriek include offering holistic robotics education, creating robotic expertise in the general public, and raising acceptance of robotics in society. Roboterfabriek involves lectures, teacher training, Robothon University, Robothon Public School, Robothon Vocational School, Robotics workshops, as well as dissemination and networking activities.

Franka Emika Panda[168] is a robot arm that manipulates objects, accomplishing tasks it is programmed to do. It is a lightweight robot system designed to assist humans. It is available for under 10,000 EUR, making it affordable for small and medium-sized companies[169].

Robothon implies five days of activities starting from building a setup,

165 Based on expert workshops
166 Based on the presentation on Successful examples of modern educational activities at Aalto University by Prof. Esko Niemi, Aalto University (Finland) at the expert workshop on "Aligning Advanced Manufacturing education and training with the 21st Century needs: Higher Education", held in Brussels on 12 June 2018
167 Based on the presentation on "The Role of Robotics in the future educational systems", by Dr. Jan Harder, Technical University of Munich (Germany) at the expert workshop on "Aligning Advanced Manufacturing education and training with the 21st Century needs: Higher Education", held in Brussels on 12 June 2018
168 https://www.franka.de/panda
169 http://www.dw.com/en/everyman-robot-panda-wins-german-presidents-future-prize/a-41591774

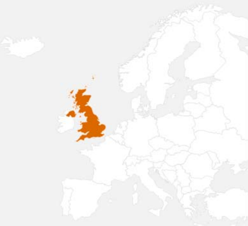
developing an approach and time plan, then moving on to realisation and finishing with optimisation and presentation. Most of the funding for the design and implementation of the activities comes from the federal government.

Initiative name: The AMRC Training Centre[170]

Institution: The University of Sheffield

Country: United Kingdom

What: Training and apprenticeships, work environment replication



Description: The AMRC Training Centre builds on the technical expertise of the Advanced Manufacturing Research Centre. Its aim is to train the skilled engineers that manufacturing businesses need to compete in global high-value markets such as aerospace and power generation. Not only the larger employers, but also the SMEs in the region. It has over 800 apprentices in training, some of them move onto part time foundation degrees, full bachelor degrees, and some aspires to do a PhD all accredited by The University of Sheffield.

The centre is set up to replicate a work environment for apprentices. This includes a variety of apprenticeship pathways and continuous professional development from mechanical manufacturing to electrical and mechanical maintenance, technical support and metals technologies, including welding and fabrication, ranging from Level 2 to Level 7.

Factory 2050 prepares the (future) workforce for the 4th Industrial revolution – the rise of the cyber-physical systems and introduces them to the next generation of manufacturing technologies. The four main research areas of the Integrated manufacturing group in Factory 2050 include Robotics and Automation, Integrated Large Volume Metrology, Digitally Assisted Assembly (DAA) and Manufacturing Informatics.

Initiative name: MIT Portugal[171]

Institution: Portuguese Foundation for Science and Technology and MIT

Country: Portugal

What: Education and research, new education paradigm

Description: MIT Portugal Program is an educational & research program. Its key focus areas include Sustainable Energy Systems, Transportation Systems,

170 Based on the presentation on "Developing world-class talent for manufacturing: Experience of the AMRC Training Centre", by Ms. Wendy Miller, the AMRC Training Centre, the University of Sheffield (United Kingdom) at the expert workshop on "Aligning Advanced Manufacturing education and training with the 21st Century needs: Higher Education", held in Brussels on 12 June 2018

171 Based on the presentation on "Teaching new technologies at BSc and MSc levels: Bringing together design and manufacturing", by Prof. Manuel Freitas, MIT Portugal (Portugal) at the expert workshop on "Aligning Advanced Manufacturing education and training with the 21st Century needs: Higher Education", held in Brussels on 12 June 2018

Bioengineering Systems and Engineering Design and Advanced Manufacturing.

The mission of Engineering Design and Advanced Manufacturing (EDAM) is to develop a new educational engineering paradigm, with high quality research closely linked to novel curricular programmes, to promote a new entrepreneurial attitude towards knowledge-based manufacturing and competitive product development. The key principles it relies on include solid scientific background, creativity, innovation, environmental and economical concern and leadership.

The mission of the Design Studio & Product Development Laboratory is to promote engineering design competencies through collaborative research and education programmes; to expand the awareness of engineering design through education, the development of new teaching curricula and materials for use in engineering and business education; and to establish public-private partnerships and industry-science relationships aimed to improve industrial competitiveness.

4.2.2. Vocational Education and Training

VET is emphasised to be key in bridging the gap between skills supply and demand[172]. As AMT develops further, the domain requires more highly skilled and specialised workers. This has direct implications for lower and medium-skilled occupancies within manufacturing. New technologies and machinery requires more specialised operators, assembly and maintenance workers, and VET needs to adapt to this. The current sub-section focusses on non-tertiary VET[173].

VET has traditionally been associated with a public provision of skills and competencies, and most of the EU Member States offer public vocational education within subjects related to manufacturing or mechanical operation[174]. We use Denmark to illustrate publicly provided VET.

The Danish VET is to a large extent provided within a public framework, through upper secondary education and adult vocational training.

Danish upper secondary education consists of two main pillars: General upper secondary education and Vocational upper secondary education and training (IVET)[175]. IVET is divided in four main domains, with one being Technology, Construction and Transport. After completing one general IVET introduction course and one domain specific introduction course, each with a duration of 20 weeks, the students are allowed to enter main programmes, which lead to specific vocational qualifications. The main programmes further provide opportunities for specialisation within the selected programme. Relevant IVET main programmes for entering advanced manufacturing are Automation and process training, CNC machining,

172 Cedefop (2018) "The changing nature and role of vocational education and training in Europe". Volume 3: "the responsiveness of European VET systems to external change (1995-2015)". Luxembourg. Cedefop research paper; No 67

173 https://eacea.ec.europa.eu/national-policies/eurydice/general/6-secondary-and-post-secondary-non-tertiary-education_en

174 See Cedefop country specific reports here: http://www.cedefop.europa.eu/en/events-and-projects/projects/vet-europe/vet-in-europe-country-reports

175 Cedefop (2012) "Vocational Education and Training in Denmark"

industrial operator, industry technician, plastics maker, process operator and industrial technician[176].

VET is also provided to adults to meet demand for new skills[177]. The programmes primarily provide sector and occupancy oriented skills and competencies. There are more than 3,000 courses available, with a selection relevant to AMT such as robotics and 3D production[178]. Completed training results in a nationally acknowledged certifications.

VET certifications within Advanced Manufacturing

The Manufacturing Institute in the United States has worked with manufacturing certification organisations to create a system of stackable credentials of vocational training within manufacturing[179]. These vary over general foundation skills and cross-cutting technical skills to specific technologies in machining and metalworking. A similar credential system does not appear to exist across advanced manufacturing in Europe. There are however, acknowledged certifications within smaller domains of advanced manufacturing provided by private suppliers. An example is ECP^2 certification for precision engineering[180].

4.2.3. On-the-job training

On-the-job training varies between different types of organisations and countries, and there is no common system of credentialing workers' skills.

Specifically for Additive Manufacturing (AM), on-the-job training today is employers' preferred choice for upskilling or reskilling workforce. It is also reported to be a "remedy" for the lack of specific knowledge in the talent pool and the difficulties in finding, among others, designers with sufficient skills. Specifically, employer's train their workers to change mind-set, unleash creativity and remove boundaries learned in engineering and design studies. Training is also required for shop floor operators, but to a lesser extent. Training is particularly needed regarding health, safety and quality control, as AM requires strict security procedures and safety measures[181].

Large manufacturing enterprises as training providers

Large enterprises have the volume and knowledge to provide sufficient training and education to new workers, and thus often become providers of on-the-job training. The structure allows for tailoring the training to the specific needs of enterprises.

Joint partnerships with technology centers and technology suppliers

On-the-job training often occurs in interaction and cooperation with leading experts, suppliers and clients. Particularly SMEs are shown to be inclined to participate in

176 Uddannelses Guiden, https://www.ug.dk/uddannelser/erhvervsuddannelser/teknologibyggeriogtransport
177 Danish Ministry of Education, http://eng.uvm.dk/adult-education-and-continuing-training/adult-vocational-training
178 https://www.efteruddannelse.dk/
179 http://www.themanufacturinginstitute.org/Skills-Certification/Certifications/NAM-Endorsed-Certifications.aspx
180 http://www.ecp2.eu/
181 Based on expert interviews

informal knowledge-intensive activities as a way of training rather than engaging in formal education[182].

Highlight 4-2: Illustrative example of AMT-related on-the-job training offer in Europe[183]

Festo Didactic (Germany, with facilities also in multiple other countries)[184]

Festo Didactic is the world-leading provider of equipment and solutions for technical education. The product and service portfolio offers customers holistic education solutions for all areas of technology in factory and process automation, such as pneumatics, hydraulics, electrical engineering, production technology, mechanical engineering, mechatronics, CNC, HVAC and telecommunications[185].

It has a broad Industry 4.0 portfolio that among others include[186]:

- Training to develop a basic understanding of the core elements and business opportunities of I4.0. This training addresses (upper) management, decision makers and executives from strategy and innovation departments.
- Training to discover the influences of digitalisation on people's private life, the impact on everyday working life and thus reducing employees' concerns towards Industry 4.0. This training focusses on the awareness raising among shop floor workers and employees of production-affiliated departments.
- Practical exercises aiming to teach the terms and technologies of Industry 4.0 and directly link them to the real production environment. This training addresses middle management, production planning and controls, R&D or innovation departments who want to start with Industry 4.0.
- Evaluating company's Industry 4.0 maturity level and defining a strategy together. Training aims to define which aspects of Industry 4.0 bring added value to the company and which actions the company can take to achieve its objectives.
- Learning about new possibilities in maintaining cyber-physical systems and getting familiar with technologies such as mobile maintenance and smart glasses. Training on CP Factory for specialists in Maintenance and Engineering/Design; etc.

4.2.4. The concept of Teaching/Learning Factories

In this sub-section, we specifically address the concept of teaching/learning factories that represent a promising environment for education, training and research especially in manufacturing-related areas[187]. The main purpose of learning factories

182 EU15 Ltd et al. (2015) "European-wide e-Learning Recognition Review Report", Erasmus+ project nr. 2014-1-UK01-KA202-001610 (SMEELEARN project)
183 Based on expert workshops
184 Based on the presentation on "New skills needed for Advanced Manufacturing & new ways to teach these skills: The Festo perspective", by Björn Sautter, Festo (Germany) at the expert workshop on "Aligning on-the-job training in Advanced Manufacturing with the 21st Century needs", held in Brussels on 18 September 2018
185 https://www.festo-didactic.com/int-en/company/?fbid=aW50LmVuLjU1Ny4xNy4xMC4zNDQ0LjQxNDE
186 https://www.festo-didactic.com/int-en/training-and-consulting/i4.0-training-portfolio/?fbid=aW50LmVuLjU1Ny4xNy4xMC44MTUwLjQ0ODI
187 Abele E., Chryssolouris G., Sihn W., Metternich J., El Maraghy H., Seliger G., Sivard G., El Maraghy W., Hummel V., Tisch M., Seifermann S. (2017) "Learning factories for future oriented research and education in manufacturing", CIPR Annals, 66, pp. 803-826

is "learning" in a "factory" environment[188]. This typically refers to the academic education of students and further education of industrial employers[189]; however, it can also be targeted at other groups. One of the key benefits of learning factories is the possibility of experiential learning, and it can imply both physical and virtual settings.

Learning factories have become widespread in recent years, particularly in Europe, and have taken many forms of facilities varying in size, scope, function, and complexity, with an aim to enhance the learning experience of students and industrial trainees in one or more areas of manufacturing engineering knowledge[190]. Learning factories are increasingly used as test areas for research. Below we list examples of existing learning factories, classified by their thematic core focus.

Learning factories for production process improvement[191]:

- PTW at TU Darmstadt (Germany);
- The Learning and Innovation Factory (LIF) for Integrative Production Education at Vienna University of Technology (Austria);
- The learning factory for advanced Industrial Engineering (aIE) at the Institute of Industrial Manufacturing and Management (IFF), University of Stuttgart (Germany);
- The LPS Learning Factory at Ruhr University of Bochum (Germany);
- The learning factory LSP for streamlined products and production management, operated by the Institute for Machine Tools and Industrial Management (iwb, TU Munich; Germany);
- The Lean Lab at NTNU in Gjøvik (Norway);
- BMW learning factory VPS (Value-Oriented Production System) Center in Munich (Germany);
- The Kärcher Learning Factory (Germany);
- The MOVE academy of the automotive, industrial and aerospace components supplier Schäffler (Germany);
- A global network of learning factories on several topics by McKinsey & Co.;
- A learning factory by Bayer and TU Berlin (Germany).

Learning factories for reconfigurability, production and factory layout planning[192]:

- The learning factory for advanced Industrial Engineering (aIE) at the Institute of Industrial Manufacturing and Management (IFF), University of Stuttgart (Germany);
- The IFA learning factory at the University of Hannover (Germany);
- The "Mini-Factory" at the University of Bolzano (Italy);

188 Wagner U., AlGeddawy T., ElMaraghy H., Müller E. (2012) "The State-of-the-Art and Prospects of Learning Factories", 45th CIRP Conference on Manufacturing Systems. Procedia CIRP 3: 109-114; cited in Abele, E., Chryssolouris, G., Sihn, W., Metternich, J., El Maraghy, H., Seliger, G., Sivard, G., El Maraghy, W., Hummel, V., Tisch, M., Seifermann, S. (2017) "Learning factories for future oriented research and education in manufacturing", CIPR Annals, 66, pp. 803-826

189 Abele E., Metternich J., Tisch M., Chryssolouris G., Sihn W., ElMaraghy H., Hummel V., Ranz F. (2015) "Learning Factories for Research, Education, and Training", 5th CIRP-sponsored Conference on Learning Factories, Procedia CIRP 32:1-6.

190 *Ibid.*

191 From Abele, E., Chryssolouris, G., Sihn, W., Metternich, J., El Maraghy, H., Seliger, G., Sivard, G., El Maraghy, W., Hummel, V., Tisch, M., Seifermann, S. (2017) "Learning factories for future oriented research and education in manufacturing", CIPR Annals, 66, pp. 803-826

192 *Ibid*.

- KTH XPRES Lab (Sweden).

Learning factories for energy and resource efficiency[193]:

- The greenfield-factory (ETA- factory) by PTW at TU Darmstadt (Germany);
- The learning factory for energy productivity by iwb at TU Munich (Germany);
- The learning factory for Resource Efficiency for Ruhr-Universität Bochum (Germany);
- The "E3-Factory" at Fraunhofer IWU in Chemnitz (Germany).

Applied teaching factory concept:

- Teaching factory at the University of Patras (Greece).

The "factory-to-classroom" teaching factory (TF) operation mode aims at transferring the real production environment to the classroom and allow students to be trained by addressing appropriate real-life engineering problems. The actual production site is used to enhance the teaching activity with the knowledge and experience existing in the processes of every day industrial practice. The "lab-to-factory" TF operation mode aims to transfer knowledge from academia to industry. Industrial-grade or didactic equipment in the academic facilities is used as test-beds and demonstrators for new technological concepts that are to be validated and introduced to industrial practice[194].

The TF paradigm has been assessed based on real-life applications together with industrial organisations. Applications indicatively included the line balancing of a new production area and the planning of a material kitting area in a construction equipment factory, the validation of a new integration and control architecture for industrial robots in an automation company, designing a Multi-Technology Platform that combines a milling working centre with a robotic arm equipped with a laser-head for a machine shop etc. The applications have demonstrated and verified the TF potential to bring together the manufacturing learning and working environments[195].

4.3. Overview of relevant initiatives

Based on extensive desk-research and stakeholder consultation, we have developed a sample of policy initiatives aiming at strengthening education and training within AMT in Europe. We first present an overview of the identified national and subnational initiatives, and then cover the EU-wide initiatives. The findings include initiatives aimed at developing specific skills related to Advanced Manufacturing, as well as initiatives of a broader AMT-related nature, where education and training represent one of the elements. For the latter, only the elements relevant to this analysis are presented. As the analysis aims at understanding the current situation, the analysis captures the initiatives that started at least in 2012 and are either ongoing or finished in 2016-2018.

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193 From Abele, E., Chryssolouris, G., Sihn, W., Metternich, J., El Maraghy, H., Seliger, G., Sivard, G., El Maraghy, W., Hummel, V., Tisch, M., Seifermann, S. (2017) "Learning factories for future oriented research and education in manufacturing", CIPR Annals, 66, pp. 803-826

194 Based on the presentation on "The Teaching Factory: A novel manufacturing education approach" by Dr. Konstantinos Georgoulias, Laboratory for Manufacturing Systems and Automation (LMS) of University of Patras (Greece) at the expert workshop on "Aligning on-the-job training in Advanced Manufacturing with the 21st Century needs", held in Brussels on 18 September 2018

195 *Ibid*.

Desk research focussed exclusively on the publicly available materials in English. Therefore, for the initiatives to be identified through desk-research, a reference in English was a necessary pre-condition. To this end, **the provided overview should by no means be treated as exhaustive or covering a wide range of local, national and European talent programs with either explicit focus on manufacturing or with a broader orientation. It rather has an indicative and illustrative nature, and aims to offer a general picture of the state-of-play regarding the relevant policy initiatives in Europe**.

4.3.1. National and subnational policy initiatives

In total, 19 relevant national and subnational initiatives were identified. This does not immediately indicate that the formal evaluation has not been performed for those initiatives, but can also stem from the fact that the search was performed in English, while the evaluation results may be available only in a local language or those may not be published on the Internet. In any case, hindered access to such information or its complete absence indicate a clear need for a higher transparency and systemisation of lessons learned, and a more rigorous assessment of impacts achieved by the relevant initiatives. Future research efforts need to be devoted to this issue. As can be seen in Table 4-2, not all of the EU Member States are covered. This might be partially explained by the non-existence of such initiatives or by lack of published and accessible information on those in English.

Our analysis suggests that there are only a few national and subnational policy initiatives explicitly focussing on education and training for Advanced Manufacturing. Most of the identified initiatives are larger programmes aimed at enhancing manufacturing and national competitiveness, with education and training being one of several pillars (e.g. national Industry 4.0 programmes).

We have identified multiple AMT-related initiatives with the aim of promoting specific technology and going from research to production[196]. It should be considered these ongoing programmes can be upscaled to promote skill bridging, education and training. Furthermore, we have identified several initiatives on enhancing STEM/digital/high-tech skills in general, but not AMT skills in particular. The Wallonian Marshall plan 4.0[197] and the activities within the Slovenian Smart Specialisation Strategy (S4)[198] are examples of such initiatives.

The identified initiatives refer to on-the-job training, VET and/or higher education. Many of the identified initiatives refer to **educating/training of highly skilled individuals**. We have also identified a few initiatives aiming at developing AMT skills in the low-educated workforce, and particularly a few aimed at young, low-educated people who do not yet have any work experience within Advanced Manufacturing.

Many of the identified initiatives have a **multi-year duration**. Some of them do not state an explicit closure date. However, most of the initiatives have secured public funding for a given period, usually 4-5 years.

Only a few of the identified initiatives provide the results of formal evaluations (e.g. MADE – Manufacturing Academy Denmark). However, most do provide general

196 See, for instance: https://www.am-motion.eu/images/AM_Inititatives_and_RDI_programmes.pdf
197 http://planmarshall.wallonie.be/mesures/vous-former-en-alternance
198 http://www.svrk.gov.si/en/areas_of_work/slovenian_smart_specialisation_strategy_s4/

references to results, often referring to the number of partners or the number of courses provided, but lacking information on the specific impact. This does not immediately indicate that the formal evaluation has not been performed for those initiatives, but can also stem from the fact that the search was performed in English, while the evaluation results may be available only in a local language or those may not be published on the Internet. In any case, hindered access to such information or its complete absence indicate **a clear need for a higher transparency and systemisation of lessons learned, and a more rigorous assessment of impacts achieved by the relevant initiatives**. Future research efforts need to be devoted to this issue.

TABLE 4-2: Overview of identified initiatives

Nr	Country	Title	Type	Coordinator	Coverage	Objectives	Target group	Duration	Evaluation/ Results
1	CZ	**National Centre for Industry 4.0**[199]	Training, promotion	National Centre for Industry 4.0	National (CZ)	To support education and teaching in the area of Industry 4.0	SMEs in Czech Republic	Initiated 2017, ongoing	Initiative now includes measures to promote investment, standardisation and applied research, as well as approaches towards cybersecurity, logistics and normalisation[200].
2	DK	**MADE – Manufacturing Academy of Denmark**[201,202]	Training, promotion, funding	MADE – Manufacturing Academy of Denmark	National (DK)	To optimise education to support world-class manufacturing	Manufacturing companies, stakeholders from research and academia	Initiated 2014. Funding from the Innovation Fund for 5 years	48 PhDs included by 2017[203]
3	FR	**Industrie du Futur**[204]	Funding, training	Alliance Industrie du Futur	National (FR)	Education of the work force to adapt skills to technological evolutions and future challenges is the third axis of the 'Industrie du Futur'	Students, unemployed, manufacturing firms	Initiated 2015, ongoing	Website of the initiative is still actively updated with success stories and industry news, attracting >700k visits per month[205].
4	FR	**Osons I'industrie**[206]	Promotion	Alliance Industrie du Futur	National (FR)	Providing information on the evolution of occupations, qualifications and skills	Young people in a situation of orientation and to employees in activity or professional retraining	Initiated 2015, ongoing	Institut Mines-Télécom together with 10 other founding members continues to lead multiple initiatives and working groups[207]

199 https://www.ncp40.eu/predstaveni
200 http://ricaip.eu/industry-4-0/czech-national-initiative/
201 http://www.made.dk/om-made/
202 European Commission (2017), "Denmark: Manufacturing Academy of Denmark (MADE)"
203 Innovationsfonden (2017), "Midtvejsevaluering af MADE"
204 https://ec.europa.eu/futurium/en/system/files/ged/fr_country_analysis.pdf
205 https://evenements.infopro-digital.com/usine-digitale/qui-sommes-nous
206 http://www.industrie-dufutur.org/osons-lindustrie/

Nr	Country	Title	Type	Coordinator	Coverage	Objectives	Target group	Duration	Evaluation/ Results
5	FR	**Grande École de Numérique**[208, 209,210]	Promotion, quality standards	Ministère de l'Economie et des Finances	National (FR)	Promotes inclusion and meets the needs of recruiters in digital skills through public acknowledgment and funding of selected courses	Young people, students	Initiated 2016	More than 400 certified courses and 11,000 people trained or in training
6	DE	**Plattform Industrie 4.0 – Work, education and training**[211]	Recommend ations	Federal Ministry for Economic Affairs and Energy and Federal Ministry of Education and Research	National (DE)	The aim of the working group is to shape the upcoming changes proactively and in collaboration with social partners.	Producers, SMEs and policymakers	The Industrie 4.0 platform was announced in 2013[212]	Published policy recommendations, business recommendations and operational best practice
7	DE	**Future Work Lab**[213]	Training	Fraunhofer-Gesellschaft	National (DE)	Ensuring that the manufacturing workforce is fit for the future of work	Managers, experts and operational staff in manufacturing companies	Initiated 2017, ongoing	More than 12k international visitors to Demonstrator World showcases[214]
8	DE	**Learning factories 4.0**[215,216]	Training	Allianz Industrie 4.0 Baden-Württemberg	Regional (Baden-Württemberg, DE)	The aim of the training factories is to prepare specialists and junior staff for the requirements of digitisation	Employers and employees in manufacturing	Initiated 2015, ongoing	More than 60 VET institutions across the region have now on-campus Learning Factories[217]

207 https://www.imt.fr/imt/labels-et-partenaires/partenariats-strategiques/limt-membre-de-lalliance-pour-lindustrie-du-futur/
208 https://www.grandeecolenumerique.fr/
209 https://www.economie.gouv.fr/files/files/PDF/DP-GEN160202.pdf
210 Grande École de Numérique, Chiffres Clés 2017, https://www.grandeecolenumerique.fr/wp-content/uploads/2018/06/ChiffresCles2017_GEN_WEBVF.pdf
211 https://www.plattform-i40.de/I40/Redaktion/EN/Standardartikel/Working-Groups/working-group-05.html
212 https://www.plattform-i40.de/I40/Navigation/EN/ThePlatform/PlattformIndustrie40/plattform-industrie-40.html
213 https://futureworklab.de/en.html
214 *Ibid.*
215 https://www.i40-bw.de/de/lernfabriken-4-0/
216 https://wm.baden-wuerttemberg.de/de/innovation/schluesseltechnologien/industrie-40/lernfabrik-40/
217 https://www.i40-bw.de/wp-content/uploads/lernfabiken-i40-bw-2019.pdf

Nr	Country	Title	Type	Coordinator	Coverage	Objectives	Target group	Duration	Evaluation/ Results
9	HU	**IPAR 4.0 National Technology Platform**[218]	Promotion	The Hungarian Academy of Science Institute for Computer Science and Control and the Ministry for national Economy	National (HU)	The objective is to find solutions and formulate recommendations to provide education, human resources and labour market strategies	Policy makers	Initiated 2014, ongoing	>70 members involved across 7 Working Groups[219]
10	IT	**Industria 4.0**[220]	Promotion, funding, training	Ministry of Economic Development	National (IT)	Development of skills through Digital Innovation Hubs, I40 Competence centres, support for educational programmes, vocational training and industrial PhDs.	Manufacturing firms, HEI and VET providers	2017-2020	200.000 academic students and 3.000 managers qualified on I4.0 topics. +100% VET enrolments around I4.0 topics. Approx. 1.400 industrial PhDs focussed on I4.0 topics.
11	LV	**National Industrial Policy Guidelines 2014-2020**[221]	Promotion	The Latvian Ministry of Economy	National (LV)	To increase number of modernised higher education programmes, implement a pilot project of apprenticeship in at least one manufacturing industry, and create proposal for the training of industry specialists by 2020	National industry, employees in manufacturing, students etc.	2014-2020	14 national industrial clusters are being supported with EU funds incl. tourism, food, life science and cleantech[222]

218 MTA Sztaki (2017), "Az IPAR 4.0 Nemzeti Technológiai Platform – Kérdoív Projekt"
219 https://www.i40platform.hu/en/about_us
220 European Commission (2017), "Italy: Industria 4.0"
221 European Commission (2018), "Latvia: National Industrial Policy Guidelines 2014-2020"
222 https://www.em.gov.lv/en/sectoral_policy/industrial_policy/clusters/clusters_in_latvia

Nr	Country	Title	Type	Coordinator	Coverage	Objectives	Target group	Duration	Evaluation/ Results
12	NL	**Smart Industry**[223]	Promotion	Smart Industry	National (NL)	Promote the perspective of employee skills as critical success factors and promotion of lifelong learning in industry production.	Employers	2014-2021	Implementation agenda was renewed in 2018[224]
13	NL	**Fieldlab**[225]	Training, certification	Smart Industry	National (NL)	Reduce the skills and knowledge gap. More than 15 relevant Fieldlabs in the domain of robotics, 3D printing, automation and smart factories.	Students, manufacturers	Initiated 2017	39 Smart Industry Field Labs currently active covering topics like personalised products and services, multimaterial 3D printing and precision agriculture
14	PT	**Pense Indústria – Nova Geração**[226]	Promotion	Centimfe – Centro Tecnológico da Indústria de Moldes, Ferramentas Especiais e Plásticos	National (PT)	To promote a new image of industry to young people	Students in elementary and secondary education	Last activity June 2015	Mulitiple activities and events organised, incl. exposure to Formula 1 events[227]
15	PT	**Industria 4.0**[228,229]	Promotion, Quality standards, funding	COTEC Portugal	National (PT)	Strengthen Portuguese industry with one main pillar being education and skills	Students in all education levels, employers, industrial stakeholders	Initiated 2016	Involved upto 100 organisations across sectors like retail, agrifood and automotive sector[230]

223 http://smartindustry.nl/wp-content/uploads/2017/07/smart-industry-actieagenda-lr.pdf
224 https://www.smartindustry.nl/wp-content/uploads/2019/03/SI-implementatieagenda-2018-DEF-LR.compressed.pdf
225 https://www.smartindustry.nl/wp-content/uploads/2018/03/Fieldlabs-poster-EN.pdf
226 http://www.centimfe.com/index.php/pt/servicos-2/formacao/pense-industria-nova-geracao
227 http://penseindustria.pt/?page_id=31
228 https://www.industria4-0.cotec.pt/en/about/
229 https://www.industria4-0.cotec.pt/en/industry-4-0-program/action-plan/
230 *Ibid*.

Nr	Country	Title	Type	Coordinator	Coverage	Objectives	Target group	Duration	Evaluation/ Results
16	SK	**Smart industry**[231]	Awareness-raising	Ministry of Economy	National (SK)	Identifying the future needs of the labour market and guiding education and skills-development in that direction	Policy makers	Initiated 2016	
17	SE	**Graduate School Produktion 2030**[232,233]	Quality standards, promotion, funding	Produktion 2030	National (SE)	The aim is to increase competitiveness in Swedish manufacturing industry, through co-operation between industry, academia and research institutes.	PhD students, Postgraduates, academics and industrial stakeholders	Initiated 2014	30 higher education courses within product and production development
18	UK	**Employer Ownership of Skills**[234,235]	Funding	UK Commission for Employment and Skills	National (UK)	Test whether employers having direct access to public funds, co-invested with their own, increased their investment in skills or allowed them to demonstrate more effective ways to improve skills in the workforce than they achieved through mainstream skills funding	Employers	First round of funding in 2012	Most employers had a positive experience. 60% of learners reported they had learned new skills. A positive aspect with EOP was the encouragement of a collaborative approach with other employers. However, there is no evidence to suggest that EOP led to increases in the number of staff trained[236]

231 European Commission (2018), "Slovakia: Smart Industry"
232 https://www.p2030graduateschool.se/graduate-school/about-the-graduate-school-31106479
233 https://produktion2030.se/wp-content/uploads/prod2030_ny_Agenda_210x230_20181.pdf
234 UKCES (2011), Employer Ownership of Skills
235 UKCES (2012), Employer Ownership of Skills Pilot – Round 2 Prospectus
236 Department for Education (2018) ,Evaluation of the Employer Ownership of Skills pilot, round 1: Final report

Nr	Country	Title	Type	Coordinator	Coverage	Objectives	Target group	Duration	Evaluation/ Results
19	UK	**Skills for innovation in manufacturing**[237]	Funding	UK Commission for Employment and Skills	National (UK)	Boost the skills and business practices needed to maximise the value of UK innovation	Employers in manufacturing sector	2015 - 2016	The main achievements of the initiative were: raising awareness amongst participating companies about innovation management[238]
20	ES	**Galicia 2030**[239]	Strategic industry analysis	Galician Enterprise University Foundation (FUEGA)	Regional (Galicia, ES)	Develop complete portfolio of professional profiles and define a map with new specialisations/degrees at University level	Regional universities of Galicia	2018-2020	A portfolio of professional profiles for the future delivered in May 2019, and detailed curricula proposals for regional universities to be delivered by May 2020

237 UKCES (2015), UK Futures Programme Competition brief: Skills for Innovation in Manufacturing
238 UKCES (2016), Evaluation of UK Futures Programme – Final Report on Productivity Challenge 4: Skill for Innovation in Manufacturing
239 https://galicia2030.es/

4.3.2. EU and international initiatives

Many of the identified initiatives for education and training in Advanced Manufacturing are partly or fully funded by the European Commission and/or at an international level. Such initiatives often represent sector cooperation with a broader objective than skill enhancement only.

The European Commission launched the New Skills Agenda in June 2016. The agenda consists of ten actions to make the right training, skills and support available for EU citizens, in particular the Blueprint for Sectoral Cooperation on Skills. Regarding the implementation of the Blueprint, the following two Erasmus+ Sector Skills Alliances[240] stand out as particularly relevant for this analysis:

- **Implementing the Blueprint for Additive manufacturing**[241]: a framework for cooperation between key stakeholders to address short and medium-term skills shortages in additive manufacturing, launching in 2018.
- **Implementing the Blueprint for Automotive sector**[242]: a framework for cooperation between key stakeholders to address short and medium-term skills shortages in the automotive sector, launched in 2017. The key objective is to address the mismatch between industry needs and education supply, particularly in the fields of digital, mechatronic, mechemtronic and transversal skills.

Through the Erasmus+ Programme, the European Commission funds a large number of projects to promote education and training in Europe. A significant share of these projects are strategic partnerships with HEIs, VET providers and businesses. Below we provide some examples of identified relevant initiatives from the Erasmus+ KA2 project overview[243] (the list is of illustrative nature and should not be considered as exhaustive).

- **CompoHUB[244] (2015-2017):** the project aimed at requalifying the labour force to enable efficient work in the high-tech domain of composite manufacturing. It aimed to do this by identifying skills gap, identify and structure occupational standards, develop and evaluate training programme, integrate learning material to digital platform and integrate training programme with VET institutions in Slovenia and Estonia.
- **Development of curricula & innovative training in robotics for smart growth of European SMEs[245] (2015-2017):** the project aimed at providing an interactive training in robotics to enhance the introduction of robotics by manufacturing SMEs. By doing so, the project aimed to contribute to increased innovation rate and higher competitiveness.

240 The Sector Skills Alliances aim at reducing the skills gap in specific sectors by working in transnational cooperation; the alliances focus on VET.
241 European Commission (2018) "A Blueprint for Sectoral Cooperation on Skills Additive manufacturing"
242 European Commission (2017) "Blueprint for Sectoral Cooperation on Skills Automotive"
243 https://ec.europa.eu/programmes/proxy/alfresco-webscripts/api/node/content/workspace/SpacesStore/d7f16371-842e-4617-8823-866bb0ccd4db/ErasmusPlus_KA2_CooperationForInnovationAndTheExchangeOfGoodPractices_Projects_Overview_2018-10-04.xls (updated 2018-10-04)
244 http://www.compohub.eu/
245 https://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/2015-1-ES01-KA202-016250

- **Automation, technology transfer and managerial practices for the growth of SMEs, a better employability and the promotion of the entrepreneurship (AuToMa)[246,247] (2016-2019):** AuToMa will contribute to ensuring high professional skills in the fields of automation, technology transfer and innovation by providing an innovative and open training approach. The approach consists of both technical and managerial learning paths and several tools focussing on specific target groups.

- **Robotics automation careers in engineering for the 21 century (RACE21)[248] (2015-2018):** The project aimed at developing new, innovative and creative curriculum in the fields of robotics and automation and thereby narrowing the gap between education and training and industry needs. It aimed to do this by collaborating with VET staff and students.

- **Development and validation of mould design and manufacturing OER from experienced labourers' know-how to complement VET[249] (2016-2018):** The initiative aimed at reducing the mismatch in skilled labour supply and demand, retain experienced knowledge, establish a closer connection between industry and training, supply quality learning material and to promote the use of digital tools in training.

- **Strategic partnership in the field of mechatronics for innovative and smart growth of European manufacturing SMEs (MechMate)[250] (2016-2018):** The project aims to promote SMEs innovativeness and competitiveness on the European and global market by providing assistance and an interactive training on mechatronics. The project aims to identify the present state-of-the-art and provide curricula, methodology, training course and guidelines for SMEs and VET providers.

- **Digital Manufacturing Training System for SMEs (Digit-T)[251] (2017-2020):** The project will provide a coherent training system that enables SMEs to get an understanding of Digital Manufacturing and overview of the associated terminology, benefits and how they can introduce Digital Manufacturing to their companies. Digit-T aims to create a free online learning platform to support this objective.

- **Enhancing EU Employability by adult training in 3D Printing[252] (2017-2019):** The project's main objective is to address the need of European industry for workforce with 3D printing skills by developing specialised training tools that would improve in a new, innovative manner the skills of adult learners. The latter boost the chances of obtaining jobs or better paid jobs and significantly enlarge the horizon of job seeking.

246 http://www.automa-project.eu/article/details/3
247 https://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/2016-1-IT01-KA202-005599
248 http://race21.epa.edu.pt/
249 https://www.up2europe.eu/european/projects/development-and-validation-of-mould-design-and-manufacturing-oer-from-experienced-labourers-know-how-to-complement-vet_64990.html
250 http://www.mechmate.eu/
251 http://www.digit-t.eu/
252 https://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/2017-1-CZ01-KA204-035528

- **FIT4FoF: Making our Workforce Fit for the Factory of the Future[253] (2018 – 2021):** project aims at addressing workers' needs, analysing technology trends across 6 industrial areas of robotics, additive manufacturing, mechatronics/machine automation, data analytics, cybersecurity and human machine interaction, to define new job profiles, which will inform education and training requirements.

- **METIS: MicroElectronics Training, Industry and Skills (2019 – 2023):** this project covers the microelectronics ecosystem, multiple stakeholder groups and all educational levels (from high school to professional courses). It is a 4-year project with an objective of establishing an EU Microelectronics Observatory & monitoring key trends (technical, social, political) and their impact on businesses' skills needs; providing education institutions with industry feedback on the needs of next generation microelectronics training; developing innovative curriculum & mechanisms of delivery (blended education: modular, work-based + online learning); Embedding sustainability & social responsibility policy principles at work; and supporting cross-border labour/student mobility in Europe.

Another important group of Erasmus+ part-funded initiatives refers to **Knowledge Alliances**. Knowledge alliances are transnational and result-driven activities between higher education institutions and businesses[254].

To identify relevant initiatives, we have reviewed the relevant projects for both Sectoral Skills Alliances and Knowledge Alliances for 2015-2018[255,256,257,258,259,260,261,262] (the list is of illustrative nature and should not be considered as exhaustive):

- **Sector Skills Alliance for advanced manufacturing in the transport sector (Skill Man)[263] (launched in 2014)**: Provides e-learning and online leaning material on certification, job roles and technology for advanced manufacturing in the transport sector.

- **MachinE Tool Alliance for Skills (METALS)[264] (launched in 2015):** Aims at boosting the competitiveness of EU machine tool industry and employability of workforce by identifying need for skills in the sector, provide quality assurance guidelines for VET providers, providing curriculum, prepare e-learning materials and an e-learning platform, promote work-based leaning and develop recognition tool for learning outcomes.

253 https://www.fit4fof.eu/
254 https://eacea.ec.europa.eu/erasmus-plus/actions/key-action-2-cooperation-for-innovation-and-exchange-good-practices/knowledge-alliances_en
255 https://eacea.ec.europa.eu/sites/eacea-site/files/essa_selection_results_2015_en.pdf
256 https://eacea.ec.europa.eu/sites/eacea-site/files/publication_ssa_selection_results_2016.pdf
257 https://eacea.ec.europa.eu/sites/eacea-site/files/selection_results_for_the_web_0.pdf
258 https://eacea.ec.europa.eu/sites/eacea-site/files/sector_skills_alliances_2018-list_of_selected_projects_for_web.pdf
259 https://eacea.ec.europa.eu/sites/eacea-site/files/v3-publication_ka_selection_results_2016-30-09-2016.pdf
260 https://eacea.ec.europa.eu/sites/eacea-site/files/updated_31oct2017-publication_ka_selection_results_2017.pdf
261 https://eacea.ec.europa.eu/sites/eacea-site/files/ka_selection_results_2018.pdf
262 https://eacea.ec.europa.eu/sites/eacea-site/files/knowledge_alliances_selection_results_2015-12-02.pdf
263 http://skillman.eu/
264 http://www.metalsalliance.eu/objectives/

- **3D Printing Skills for Manufacturing (3DPrism)[265] (launched in 2016):** Aims to enhance the added value of 3D printing in manufacturing 3DPRISM support VET provision on 3D printing skills, contribute to implementation of EU policies and identify new occupational profiles in the manufacturing sector.

- **Skills in Metal and Electro Industry (SkillME)[266] (2014-2017):** A collaboration between VET providers, national authorities and metal and electro industries to identify differentiating skills gap and developing curricula accordingly.

- **MAKE-IT[267] (launched in 2016):** MAKE-IT aimed to develop a European sector oriented qualification system and establish a scheme for Recognition of Prior Learning for the welding sector. Thereby the project aimed to allow for the redefinition of the 'welding practitioner' professional profile and address the need for qualified people in welding technology.

- **Industry 4.0 CHAlleNGE: Empowering Metalworkers for Smart Factories of the Future (4CHANGE)[268] (2016-2019):** The main mission of the project is to tackle the skills gap of metalworkers. The project will therefore design and deliver a new VET programme based on current and future skills demand, and develop a self-adaptive work-based learning system.

- **Mechatronics and Metallurgical VET for sectors' industries (MeMeVET) (2018-2019)[269]:** The primary objective of the project is to enhance mobility in the mechatronics and metallurgical sector. Additional objectives are to enhance inter-generational learning through VET and the promotion of necessary skills, qualifications and good practice at a European level. It will provide a common curriculum for complementary educational skills in the five participating countries and an e-card for EU CV for uploading of all acquired complementary educational skills in mechatronics and metallurgical sector.

- **Creating knowLedge and skilLs in AddItive Manufacturing (CLLAIM)[270] (launched in 2018)**: The project aims to create a European Advance Manufacturing qualification system. It is necessary to design new training curricula and assessment tools and introducing innovative training approaches.

- **Development and Research on Innovative Vocational Education Skills (DRIVES) [271] (2018-2021):** The project will deliver human capital growth solutions for the automotive industry, covering all levels of the value chain. It will build on the GEAR 2030 project and create tools to reduce future skills gap and shortages, enhance the recognition of formal and informal automotive education and adapt the apprenticeship marketplace to the sector's needs.

- **Open Design and Manufacturing (OD&M)[272] (launched in 2018):** The OD&M Knowledge Alliance aims to achieve in-depth understanding of the OD&M

265 https://3dprism.eu/
266 https://www.gzs.si/skill-me/vsebina/O-nas
267 http://makeitproject.eu/project.html
268 http://change4industry.eu/en/pages/home/about-project.html
269 http://www.memevet.eu/
270 http://cllaimprojectam.eu/index.html
271 http://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/443fbc62-25f7-4121-94c4-3c65ff67b258
272 https://odmplatform.eu/

paradigm in business models and production processes, as well as understanding which new knowledge, competencies and skills are needed to boost it at meaningful scale.

- **Knowledge Alliance for AdDitive Manufacturing between Industry and univeRsitiEs (ADMIRE)[273] (launched in 2017):** ADMIRE responds to an urgent industrial need for qualification of Additive Manufacturing workforce. In collaboration with universities, companies and students it will develop a Metal AM Master degree.

- **Knowledge Alliance for Upskilling Europe's SMEs to meet the Challenges of Smart Engineering (SMeART)[274] (2017-2019):** The objective is to bring recent research and practical SME know-how together to make manufacturing SMEs 'smart'. They will do it by designing, testing and integrating a research-business cooperation model for upskilling manufacturing SMEs.

In addition, the Erasmus+ programme funds a large number of **degrees and mobility programmes** to promote mobility and skills enhancement in Europe[275]. The orientation of supported degrees can promote upskilling in also in Advanced Manufacturing

Furthermore, the **European Institute of Innovation & Technology** was established to promote innovation across Europe. A new innovation community for Advanced Manufacturing, **EIT Manufacturing**[276,277,278], was launched in December 2018. A key target is to integrate education in the cooperation between business and research and by developing sector or skill specific education programmes.

Finally, **Cedefop** runs several projects on vocational training and preparing the workforce for the future. Relevant project for this initiative are for example **Forecasting Skills Demand and Supply**[279] and **Digitalisation and the Future of Work**[280].

The curriculum guidelines to be developed in the context of the current initiative also need to take into account the renewed **EU Industrial Policy Strategy[281]** and the initiatives under the European Commission's **Smart Specialisation Platform for Industrial Modernisation** (S3P-Industry)[282].

With regard to international initiatives, a prominent example refers to the **CDIO initiative**[283], representing an innovative educational framework for producing the next generation of engineers. The framework aims to provide students with an education stressing engineering fundamentals set in the context of **Conceiving — Designing — Implementing — Operating** (CDIO) real-world systems and products. CDIO

273 http://admireproject.eu/goal.html
274 http://www.smeart.eu/
275 https://eacea.ec.europa.eu/erasmus-plus/actions/key-action-1-learning-mobility-individuals
276 https://eit.europa.eu/eit-community/eit-glance
277 https://eit.europa.eu/collaborate/2018-call-for-proposals
278 https://eit.europa.eu/activities/education
279 http://www.cedefop.europa.eu/en/events-and-projects/projects/forecasting-skill-demand-and-supply
280 http://www.cedefop.europa.eu/en/events-and-projects/projects/digitalisation-and-future-work
281 https://ec.europa.eu/commission/news/new-industrial-policy-strategy-2017-sep-18_en
282 http://s3platform.jrc.ec.europa.eu/industrial-modernisation
283 http://www.cdio.org/about

Initiative collaborators have adopted CDIO as the framework of their curricular planning and outcome-based assessment in many parts of the world. The CDIO Initiative was developed with input from academics, industry, engineers, and students. It was specifically designed as a template that can be adapted and adopted by any university engineering school. It is an open architecture model available to all university engineering programs to adapt to their specific needs. CDIO is currently in use in university aerospace, applied physics, electrical engineering, and mechanical engineering departments[284].

4.4. Overview of key publications

The current section provides an overview of the latest scientific, policy and business publications.

4.4.1. Overview of relevant scientific publications

An extensive screening of scientific publications was performed based on their relevance to the topic of education and training in Advanced Manufacturing. The topic was addressed from a broad perspective and included the literature screening for HE, VET and on-the-job training in AMT. We aimed at selecting the *most recent* publications on the topic (not older than 2014), with focus on the opportunities, challenges and solutions in the context of AMT-related education and training. After an extensive search, we developed a **sample of ten scientific publications** having a high relevance to the topic of analysis. The sampling was performed following a pragmatic approach and identifying publications that explicitly address the topic. The current overview by no means aimed to represent a comprehensive analysis of the scientific literature in the field, and was rather meant to illustrate relevant publications.

Table 4-3 provides an overview of the screening results. The selected publications are presented in the chronological order (starting from the most recent one). A complete list of scientific publications used for the analysis within this initiative is provided in Annex F.

A prominent pattern in the identified literature refers to **the need for close cooperation between education and training providers and industry**[285,286]. Involving industry in education and training is considered to be a key element in ensuring that workers are trained in skills demanded by the industry. Related solutions among others include learning (teaching) factories[287,288], apprenticeships, web-based virtual learning, gamification and expert centres.

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284 http://www.cdio.org/about
285 See, for example, Huang, Y. and Leu, M.C. (2014), "Frontiers of Additive Manufacturing Research and Education", University of Florida, Report of NSF Additive Manufacturing Workshop
286 See, for example, Matt D. T., Rauch, E., Dallasega, P. (2014) "Mini-factory - A Learning Factory Concept for Students and Small and Medium Sized Enterprises", Procedia CIRP, 17, pp. 178-183
287 Abele, E., Chryssolouris, G., Sihn, W., Metternich, J., El Maraghy, H., Seliger, G., Sivard, G., El Maraghy, W., Hummel, V., Tisch, M., Seifermann, S. (2017) "Learning factories for future oriented research and education in manufacturing", CIPR Annals, 66, pp. 803-826
288 Abele, E., Chryssolouris, G., Sihn, W., Metternich, J., El Maraghy, H., Hummel, V., Tisch, M., Ranz, F. (2015) "Learning factories for research, education, and training", Procedia CIPR, 32, pp. 1-6

TABLE 4-3: Overview of key scientific publications

Nr	Publication
1.	Bonnaud O. (2019) "**New Vision in Microelectronics Education: Smart e-Learning and Know-how, a Complementary Approach**". © Springer International Publishing AG, part of Springer Nature 2019 V. Uskov et al. (Eds.): KES-SEEL-18 2018, SIST 99, pp. 267–275, 2019.
2.	Abele, E., Chryssolouris, G., Sihn, W., Metternich, J., El Maraghy, H., Seliger, G., Sivard, G., El Maraghy, W., Hummel, V., Tisch, M., Seifermann, S. (2017) "**Learning factories for future oriented research and education in manufacturing**", CIPR Annals, 66, pp. 803-826
3.	Tsoy, T., Sabirova, L., & Magid, E. (2017) "**Towards Effective Interactive Teaching and Learning Strategies in Robotics Education**", in Developments in eSystems Engineering (DeSE), 2017 10th International Conference on (pp. 267-272), IEEE.
4.	Kolmos, A., Hadgraft, R. G., & Holgaard, J. E. (2016) "**Response strategies for curriculum change in engineering**", International Journal of Technology and Design Education, 26(3), pp. 391-411. doi:10.1007/s10798-015-9319-y
5.	Go, J., Hart, A. J. (2016) "**A framework for teaching the fundamentals of additive manufacturing and enabling rapid innovation**", Additive Manufacturing, 10, pp. 76-87
6.	Abele, E., Chryssolouris, G., Sihn, W., Metternich, J., El Maraghy, H., Hummel, V., Tisch, M., Ranz, F. (2015) "**Learning factories for research, education, and training**", Procedia CIPR, 32, pp. 1-6
7.	Kolmos, A., & Graaff, E. d. (2014) "**Problem-Based and Project-Based Learning in Engineering Education: Merging Models**". In B. M. Olds & A. Johri (Eds.), Cambridge Handbook of Engineering Education Research. (pp. 141-161.): New York, NY, USA: Cambridge University Press.
8.	Matt D. T., Rauch, E., Dallasega, P. (2014) "**Mini-factory - A Learning Factory Concept for Students and Small and Medium Sized Enterprises**", Procedia CIRP, 17, pp. 178-183
9.	Hamid, M. H., Masrom, M., Salim, K. R. (2014) "**Review of Learning Models for Production Based Education Training in Technical Education**", International Conference on Teaching and Learning in Computing and Engineering (LaTiCE)(LATICE), pp. 206-211.
10.	Rentzos, L., Doukan, M., Mavrikios, D., Mourtzis, D., Chryssolouris, G. (2014) "**Integrating Manufacturing Education with Industrial Practice Using Teaching Factory Paradigm: A Construction Equipment Application**" Procedia CIRP, 17, pp. 189-194

4.4.2. Overview of relevant policy and business publications

Additionally, an extensive screening of business and policy publications was performed. The identification of the relevant sources was done by means of expert consultation and targeted desk-research. Also here, we aimed at selecting the *most recent* publications on the topic (not older than 2014), with focus on the opportunities, challenges and solutions in the context of education and training in AMT (including VET, HE and on-the-job training). We selected **a sample of ten business and policy publications** having a high relevance to the topic. The sampling was again performed following a pragmatic approach and identifying publications that explicitly address the topic in question. The current overview again by no means aims to represent a comprehensive analysis of the policy and business literature in the field, and rather means to illustrate the latest publications. A complete list of policy and business publications used for the analysis within this initiative is provided in Annex F.

Table 4-4 provides an overview of results. The selected publications are presented in the chronological order (starting from the most recent one).

Nr	Publication
1.	WEF (2019) "**A Global Standard for Lifelong Learning and Worker Engagement to Support Advanced Manufacturing**", White Paper of the World Economic Forum, October 2019
2.	Eurofound (2019) "**The future of manufacturing in Europe**", Publications Office of the European Union, Luxembourg, April 2019
3.	High-Level Expert Group on the Impact of the Digital Transformation on EU Labour Markets (2019) "**The Impact of Digital Transformation on EU Labour Markets**", report of the High-Level Expert Group, April 2019
4.	Impuls Foundation (2019) "**Impuls compact: Engineers for Industrie 4.**0", VDMA (The Mechanical Engineering Industry Association), March 2019

Nr	Publication
5.	WEF in collaboration with Boston Consulting Group (2019) "**Towards a Reskilling Revolution: Industry-Led Action for the Future of Work**", Centre for New Economy and Society Insight Report, January 2019
6.	Bialik M. and Fadel C. (2018) "**Knowledge for the Age of Artificial Intelligence: What should students learn?**", Center for Curriculum Redesign, January 2018
7.	Graham R. (2018) "**The global state of the art in engineering education**", MIT School of Engineering, March 2018
8.	Moghaddam Y. et al. (2018) "**T-shaped professionals: Adaptive innovators**", Service Systems and Innovations in Business and Society Collection, Business Expert Press
9.	Kamp. A (2016) "**Engineering Education in the Rapidly Changing World: Rethinking the Vision for Higher Engineering Education**", 2nd revised edition, Delft University of Technology and 4TU.Centre for Engineering Education
10.	VDI (2015) "**A Discussion of Qualifications and Skills in the Factory of the Future: A German and American Perspective**", VDI

4.5. Descriptions of good practice curricula

Within the first phase of this initiative, we have also developed illustrative descriptions of 10 good practice curricula for education and training in AMT-related domains. These curricula have been identified **based on the QS World University Rankings by Subject 2018**[289] (the overall ranking is based on four indicators, namely academic reputation, employer reputation, citations per paper and h-index citations[290]). The ranking is available per subject at the level of Engineering and Technology sub-domains (e.g. Electrical engineering, Mechanical engineering, Chemical engineering). Although the ranking is not explicitly focussed on AMT, it can still be a good proxy of the quality of offered education at a specific university, and thus allows to select the top academic actors in Europe.

For this purpose, we applied a filter of "Engineering - Mechanical, Aeronautical & Manufacturing; top ranking university per country", and selected top 5 universities *in Europe* from 5 different Member States. For each university, we then performed a screening of available educational programmes for their relevance to AMT, and selected one AMT-related Bachelor and one Master programme per university for a more detailed analysis. This exercise resulted in a sample of 10 good practice curricula. Table 4-5 provides an overview of the selected programmes and corresponding curricula.

TABLE 4-5: Overview of selected good practice curricula

Nr	Education provider	Country	Programme title
1.	University of Cambridge	United Kingdom	Manufacturing Engineering Tripos
2.	University of Cambridge	United Kingdom	MSc. Industrial Systems, Manufacturing and Management
3.	Delft University of Technology	Netherlands	BSc. Industrial Design Engineering
4.	Delft University of Technology	Netherlands	MSc. Mechanical Engineering
5.	Politecnico di Milano	Italy	BSc. Industrial Production Engineering
6.	Politecnico di Milano	Italy	Global Master in Industrial Management
7.	RWTH Aachen University	Germany	BSc. Materials and Process Engineering Specialization
8.	RWTH Aachen University	Germany	MSc. Materials and Process Engineering Specialization

289 https://www.topuniversities.com/subject-rankings/2018
290 https://www.topuniversities.com/university-rankings/university-subject-rankings/2015/materials-sciences

Nr	Education provider	Country	Programme title
9.	KTH Royal Institute of Technology	Sweden	BSc. Mechanical Engineering
10.	KTH Royal Institute of Technology	Sweden	MSc. Production Engineering and Management

For each of the selected curricula, detailed curricula descriptions were then developed based on desk-research and, whenever needed, stakeholder consultations (coordinators of the corresponding educational programmes). The curricula descriptions contain information on the general characteristics of an educational programme, its objectives and essence, relevance to addressing the new skill needs, curriculum framework, delivery mechanisms and impact. The outcome of this exercise is presented in *Annex D* of this report. The collected insights will serve as inputs for the further development of the curricula guidelines, as will be presented in Chapter 5 of this report. As highlighted above, the presented curricula descriptions are of *illustrative* nature. They serve the purpose of demonstrating the actual implementation of the suggested education and training principles in practice and (whenever relevant) provide the corresponding impact assessment.

4.6. Key barriers and solutions

In the current section, we pay special attention to the **key barriers for the successful transformation of the AMT-related education and training system**, and briefly address the corresponding solutions.

Many great recent examples of educational innovations exist, and they have successfully been implemented in some settings. However, **the mainstream education and training system remains extremely difficult to change**, demonstrating a whole set of barriers. While the main purpose of this initiative is to develop the detailed curriculum guidelines proposing specific solutions for change, it is crucial to acknowledge the overall context in which this change can or cannot happen, and thus also to address these key barriers.

Barriers for change in education and training systems

Educational system has been historically slow to adopt innovations for many reasons[291]. Without interest or external pressures, educational institutions in their majority (not just recently but) for centuries have demonstrated a clear resistance to systemic change, with even the smallest reforms being held off for years if not decades[292]. Innovation is difficult to spread across the education and training system because it disrupts the established routine[293]. In many cases, educational institutions choose to preserve the status quo. Innovation, in turn, whether it refers to technology, delivery mechanisms, assessment or other aspect, requires time and space for experimentation and a high tolerance for uncertainty[294].

291 See, for example, Marcus, J. (2012), "Old school: four-hundred years of resistance to change", in Wildavsky, B., Kelly, A. and Carey, K. (Eds), Reinventing Higher Education: The Promise of Innovation, Harvard Education Press, Cambridge, MA, pp. 41-72; and Hoffman A. and Holzhuter J. (2012), "The evolution of higher education: innovation as natural selection", in Hoffman, A. and Spangehl, S. (Eds), Innovation in Higher Education: Igniting the Spark for Success, American Council on Education, Rowman & Litttlefield Publishers Inc., Lanham, MD, pp. 3-15.

292 Wildavsky B., Kelly A. P., & Carey K. (Eds.) (2011) "Reinventing higher education: The promise of innovation", Harvard Education Press.

293 Serdyukov P. (2017) "Innovation in education: what works, what doesn't, and what to do about it?", Journal of Research in Innovative Teaching & Learning, 10(1), 4-33.

294 *Ibid*.

Specific barriers for change in education and training systems include the following:

- **Teachers/trainers and administrators are often cautious about top-down induced change** and have limited tolerance for the uncertainty that any major innovation causes[295]. This is supported by the fact that teachers/trainers typically do not get rewarded for introducing change, and may even be "punished" for deviating from the agreed conventional approach.

- **Lack of trust to teachers/trainers when it comes to initiating innovation:** teachers/trainers need to have freedom to innovate in the implementation, security on the job to take risks, and control of what they are doing. Ultimately, they need be trusted to do their job right[296].

- **Innovation in education and training is not promoted/supported in a top-down way meaning lack of educational leadership in creating visions, strategies and incentives**: as emphasised above, with lack of support from the top, there is little incentive for teachers/trainers to develop and adopt innovations. Innovation needs to be put at the centre of the strategy of education providers, and the required support from the top goes beyond the organisational limits, and also includes national and EU governments.

- **Significant efforts are needed to upscale innovations**: while developing and implementing innovation on a small scale is already a complex task, scaling it up and spreading it across multiple educational institutions in a region, country or Europe is an even more challenging mission. It often requires multi-stakeholder engagement, complex project management and considerable budgets.

- **Lack of access to infrastructure and the need for high capital investments**: AMT-related education and training often implies the use of modern equipment and infrastructure, which, in turn, is associated with high capital investments and/or proximity to specific locations. Furthermore, once acquired, machines also quickly become outdated. Many of the education and training providers therefore cannot afford buying state-of-the-art equipment.

- **Leaving students/learners out of the equation**: existing good practice initiatives often aim to improve teaching (delivery), while what is actually needed is to improve *learning*. The ultimate goal should be not so much to learn a specific subject, but to cultivate innovative people able to grow their autonomy, self-efficiency, and foster an entrepreneurial mindset[297].

AMT is evolving fast, making it challenging for educational providers to keep curricula up-to-date and to provide insight on the latest technologies. Some of the technologies (e.g. 3D-priniting) are not yet fully industrialised, and universities might be less willing to fully commit to developing and providing educational offers in these domains. For VET, access to machinery is a key barrier, as the machinery is highly expensive. To obtain relevant training, it is important to follow a hands-on approach and have

295 Serdyukov P. (2017) "Innovation in education: what works, what doesn't, and what to do about it?", Journal of Research in Innovative Teaching & Learning, 10(1), 4-33.
296 *Ibid*.
297 *Ibid.*

physical access to the machinery. Adding to the challenges, machines quickly become outdated in such a fast evolving-market. Finally, educational institutes and training providers tend to focus on purely technical issues, and less on standards or regulations which are also important in growing these technologies[298].

Solutions to stimulate change in education and training systems

The solutions to address the abovementioned barriers can be grouped into the following key **directions for action**:

- **Organising education and training around learners rather than teachers/trainers**: developing education and training ecosystems where learners and their needs are put in the center, with the main focus on learning rather than teaching;

- **Promoting innovation in teaching/training**: rewarding educational institutions and teachers/trainers for introducing innovative approaches; these aspects need to be embedded in the assessment schemes for both organisations and individuals;

- **Regularly updating the skills of teachers/trainers**: sending the educational personnel to companies to get insights into the latest developments, while inviting people from companies to regularly teach in the classroom;

- **Equipping teachers/trainers with the needed tools and skills to implement innovation**: developing relevant tools and platforms, creating collaborative spaces for exchanging experiences and sharing good practices;

- **Actively involving companies in the development and implementation of education and training curricula**, including the identification of desired learning outcomes, curricula design, actual teaching/training, assessment and recognition;

- **Exploring alternative forms of accessing equipment and infrastructure**: e.g. sharing costs with other parties, renting equipment from industry, employing Augmented Reality/Merged Reality/Virtual Reality (AR/MR/VR) solutions etc.;

- **Convincing companies about the benefits of employee training**: encouraging employers to invest in up-skilling of their personnel by offering them factual evidence and by showcasing good practices.

The specific solutions within each of the identified directions for action have been partially addressed in detail by PwC in the context of the "Vision and Sectoral Pilot on Skills for Key Enabling Technologies" initiative (2014 – 2016) (hereafter "KETs Skills Initiative") for DG GROW of the European Commission[299]. In the context of the current initiative, we aim to further tailor these solutions to the needs of the AMT domain. The

298 Based on expert interviews
299 PwC (2016) "Final report on Vision and Sectoral Pilot on Skills for Key Enabling Technologies", prepared for DG GROW of the European Commission, Service contract nr. SI2.ACPROCE060233200

resulting implications for teacher training have also been addressed in more detail in section 3.2.5 of this report.

5. CURRICULUM GUIDELINES 4.0

The previous chapters have illustrated that we are in the age of digital manufacturing. Skill requirements are changing rapidly, and companies struggle to find the talent they need. How can education and training keep pace with this unprecedented level of change? How does a future-proof curriculum look like?

The current initiative specifically aimed to produce curriculum guidelines for Europe's education and training providers, highlighting the key points of attention and good practice examples, when it comes to aligning their approach with the needs of the new age. The guidelines were developed based on the extensive state-of-play analysis and active stakeholder contribution by means of six expert workshops[300], two pan-European online surveys, sixty in-depth interviews and individual expert consultations. The guidelines were first presented to the public at a European conference in Brussels on 26 November 2019. All key stakeholder groups were involved in the preparation of the guidelines, including the representatives of education and training providers, industry, policy makers and supporting structures (e.g. industry associations, cluster organisations and trade unions), as well as learners themselves. The current chapter presents the outcomes of this analysis.

When developing the guidelines, there was first a need to have a common definition of the curriculum. The selected approach implied a shift from a narrow perspective, viewing the curriculum as a list of subjects to be taught, towards a broader perspective, characterising the **curriculum as the overall learning experience** of individuals (and groups) not only in schools, but throughout their professional lives[301]. To this end, the Curriculum Guidelines 4.0 address the new ways of organising learning experiences of individuals and groups for the manufacturing industry of the future.

This vision is well aligned with the recommendations of UNESCO-IBE stating that "*the curriculum understood only as study plans organised around disciplines with lists of goals and contents, does not seem to contribute to a renewed vision of the education system as a facilitator of learning opportunities*"[302]. The curriculum, however, may become a vital catalyst if it results from a process engaging stakeholders and as a reflection of a society's aspirations and vision for its future, involving a diversity of institutions and actors, and clearly focusing on the what, why and how of education. It is therefore crucial **to ensure a wider policy dialogue** around curriculum design and development, with the active involvement of other actors besides the traditional ones[303].

5.1. Developing curricula for the VUCA world

Curriculum development must reflect the true nature of the world. The world, in turn, is changing with an unprecedented speed, increasing our inability to grasp the change and deal with the developments happening around us. For several years, the term

300 For more information about the workshops, please refer to Annex A.
301 Hartoyo (2011) "A Handout about Curriculum and Material Development in English Language Teaching"
302 UNESCO-IBE (2013) "The Curriculum Debate: Why it is Important Today", IBE Working Papers on Curriculum Issues Nr. 10
303 *Ibid*.

"VUCA" is gaining popularity as a notion that covers the various dimensions of this 'uncontrollable' environment[304]. VUCA stands for:

- **V**olatility: high speed of change in industry, market and the world in general; fluctuations in demand, turbulence, short time to markets;
- **U**ncertainty: different scenarios are possible, it is difficult to make predictions;
- **C**omplexity: the immense number of factors that need to be taken into account, with a high variety and complex relationships between them; *and*
- **A**mbiguity: a need to deal with incomplete, contradicting or too inaccurate information to draw conclusions.

Providing relevant education and training in the VUCA world is anything but an easy task. It requires a mind-set shift, with an aim to convert uncontrollable chaos into manageable complexity. The latter can be achieved with the help of the following four elements:

- **V**ision: anticipating change; not just predicting but creating the future;
- **U**nderstanding: making informed decisions based on best available data;
- **C**ommitment: investing effort to transform vision into reality;
- **A**gility: adapting efficiently and fast to constantly changing circumstances.

The Curriculum Guidelines 4.0 aim to offer key guiding principles that could assist education and training providers with a shift from the uncontrollable VUCA towards the more manageable VUCA, when developing and implementing their curricula.

Specifically, the Curriculum Guidelines 4.0 were developed keeping the following principles in mind:

- **Shared**: the curriculum guidelines have to be driven and supported by all key stakeholder groups including SMEs and other industry, education and training providers, policy makers at all levels, and last but not least, learners themselves.
    - Rather than a product of the top-down approach, they need to be the result of stakeholder co-creation efforts in order to ensure its maximum practical relevance and acceptance by the relevant publics.
- **Efficient**: the curricula guidelines have to build on economically attractive solutions allowing for the optimal use of time, effort and cost.
- **International**: educating and upskilling AMT professionals imply intensive cross-border cooperation. The ability to work in an international environment is one of the key required skills. The guidelines therefore have to be applicable to diverse cultural and geographical contexts and foster international cooperation.
- **Multi-level**: in order to tackle the identified skills challenges, actions need to be taken at various levels including the EU and MS (and if relevant, local multi-stakeholder initiatives). The guidelines therefore have to offer a strategic platform that can be further operationalised into specific action points at each of the abovementioned levels.

304 Kraaijenbrink J. (2018) "What does VUCA really mean", Forbes, 19 December 2018

- **Covering various sectors and technologies**: the guidelines have to acknowledge the multidisciplinary nature of AMT.

- **Long-term oriented**: the guidelines have to be primarily of mid-term orientation and cover the period 2021-2027 (but also beyond). The period of 5-10 years can still be viewed as a relatively short time period for educating/upskilling the AMT professionals, and the associated skills that need to be available.

    - The total length of the innovation cycle depends on the sector and the type of innovation, but for highly complex technologies, it often is 15 to 20 years long· Hence such technologies require a **consistent multi-year programmatic approach**.

    - Therefore, the year 2027 should not be seen as the final destination point, but rather as an intermediate milestone in a much longer trajectory of the smart industrial specialisation and digital transformation and the upskilling of the workforce in Europe, the process that is likely to continue for decades to come.

- **Ability to survive the changes of scope and timescales**: the guidelines have to set the general strategic orientation; however, they have to be flexible enough and allow for adjustments and future revisions.

    - One of the key characteristics of the evolving learning landscape is its high pace of change. The same refers to the world of AMT. Consequently, developing solid 'set-in-stone' guidelines would contradict the very nature of them. Instead, we will aim at capturing the key directions for development in the coming years, and operationalising them into a set of specific action points that could be relatively easily adjusted, if necessary.

- **Offering an opportunity to develop customised (tailor-made) curricula**: There is no single recipe for developing an effective curriculum. Curricula are living, dynamic entities in constant flux. Instead of offering rigid solutions, we therefore aim at offering flexible options and illustrative/model examples.

5.2. Curriculum Guidelines Framework

In order to ensure a systemised analysis, there was a need for a framework that would allow for effective structuring of the collected inputs and clustering of the derived findings. The developed framework (see Figure 5-1) is the result of collective effort, implying active stakeholder engagement and co-creation. The framework was specifically designed, fine-tuned and validated by means of individual expert consultations and multiple expert workshops. The objective of the framework is to provide **a holistic overview of all key elements relevant for curriculum design and implementation from broader perspective**, namely viewing the curriculum as the overall learning experience of individuals (and groups) throughout their professional lives. The framework (hereafter "Curriculum Guidelines Framework") serves as an analytical structure for plotting the identified conceptual principles and good practice examples.

The Curriculum Guidelines Framework was thus custom-made specifically to serve the needs of the current initiative. Various existing frameworks were examined by the project team for potential use in the context of this assignment, such as, for example, Curriculum Design and Implementation model by CDIO (Conceiving — Designing — Implementing — Operating)[305], or the 4C/ID-model developed originally by van Merriënboer and others in the early 1990s (van Merriënboer, Jelsma, & Paas, 1992) for the design of training programs for complex skills[306]. While these prominent framework are highly relevant for the current discussion, they have more operational/instructional nature[307], while the purpose of this analysis is to extract the key elements of the **"bigger picture" when it comes to developing curricula for the new age**. Rather than offering detailed structured algorithms, the current analysis aims to sketch the key conceptual considerations and indicate sources and good practice examples for inspiration and further information. To this end, a new conceptual framework was designed to match the abovementioned requirements.

The Curriculum Guidelines 4.0 aim to emphasise that **there is no one size fits all approach**, and instead, there is a need to respect and cultivate a diversity of approaches, as the effectiveness of a certain approach is likely to vary depending on the objectives, context and other contingency factors. As can be seen from the Figure, the Curriculum Guidelines Framework consists of the following eight distinctive but interconnected elements: (1) Strategy; (2) Collaboration; (3) Content; (4) Learning environment; (5) Delivery mechanisms; (6) Assessment; (7) Recognition; *and* (8) Quality.

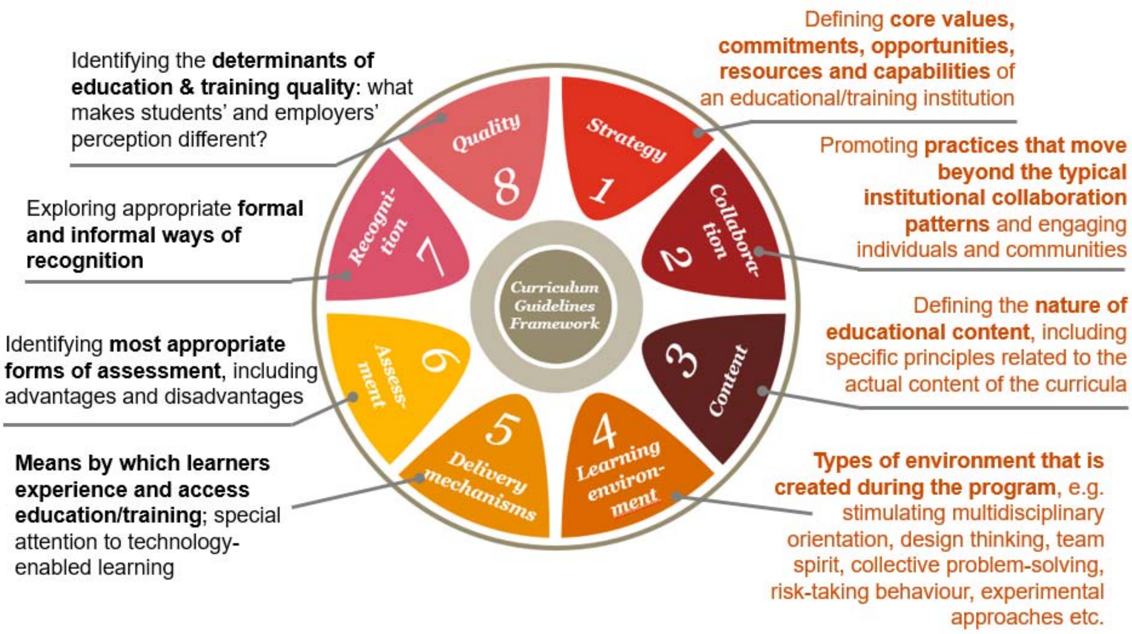


FIGURE 5-1: Curriculum Guidelines framework

305 http://www.cdio.org/implementing-cdio-your-institution/implementation-kit/curriculum/design-and-implementation

306 https://www.researchgate.net/profile/Jeroen_J_G_Van_Merrienboer2/publication/225798787_Blueprints_for_complex_learning_The_4CID-model/links/0912f5100d35ede27a000000.pdf

307 For example, the 4C/ID-model is meant to be used at a micro-level of education, and can hardly be applied to meso- (institutional) and macro- (policy) levels.

Strategy (1) refers to defining core values, commitments, opportunities, resources and capabilities of an educational/training institution with respect to developing a 21st century curriculum for AMT. The focus here is put on the conceptual aspects of the educational offer. Specifically, the elements of strategy include assessing learner's needs, developing curriculum goals and intended learning outcomes.

Collaboration (2) refers to connecting individuals and institutions by facilitating the exchange of practices and resources with a view to improve the educational offer. Special attention is paid to practices that move beyond the typical institutional collaboration patterns and engaging individuals and communities. The analysis also aimed to address practices that empower learners to collaborate with each other and with the institution and community in order to produce knowledge, define their unique learning paths and achieve their goals.

The **Content (3)** dimension refers to the nature of educational content and includes specific conceptual principles related to the actual content of the curricula (i.e. syllabus design principles).

Learning environment (4) includes types of environment that is created during the programme in order to meet the objectives of the educational offer, e.g. stimulating multidisciplinary orientation, design thinking, team spirit, collective problem-solving, risk-taking behaviour, experimental approaches etc.

Delivery mechanisms (5) refer to the means by which learners experience and access education/training, and include in-person delivery where teachers/trainers and learners interact face-to-face (e.g. lectures, seminars, workshops); electronic delivery (synchronous and asynchronous), and blended delivery (education that combines multiple types of delivery). Here, the analysis aims at addressing the role of technology-enabled learning, including traditional e-learning, MOOCS, SPOCs, m-learning, gaming, virtual and augmented reality, AI solutions etc.

The analysis also implies examining the most appropriate forms of **assessment (6)**, e.g. self-assessment through which learners can monitor and evaluate their own learning (trains the ability to be reflective and self-critical); peer assessment, in which learners provide feedback on each other's learning; tutor/institutional assessment, in which the assessment is performed based on the judgement of tutor or standardised assessment test; other alternative forms of assessment. The aim is to identify which assessment types are suitable for what type of educational offer.

Recognition (7) refers to the process, usually carried out by an accredited institution, of issuing a certificate, diploma or title which has formal value; and the process of formally acknowledging and accepting credentials, such as a badge, a certificate, a diploma or title issued by a third-party institution. Within this dimension, the analysis aims at exploring appropriate formal and informal ways of recognition.

Finally, the framework also aims to cover the determinants of education and training **quality (8)**: what makes learners' and employers' perception different? It specifically refers to good practice examples in quality assurance.

The inputs for each element of the curriculum guidelines framework were collected by means of targeted desk-research, and with **active stakeholder engagement** via expert workshops, online surveys, as well as in-depth interviews and individual stakeholder consultations. The project team specifically disseminated an input form template among the experts, with a request to provide their suggestions for the specific elements of the guidelines. The approached stakeholders were requested to share the relevant good practice examples illustrating successful approaches, as well as specific data sources containing relevant information on the analysed topics. The stakeholders were also invited to comment on the overall design of the framework.

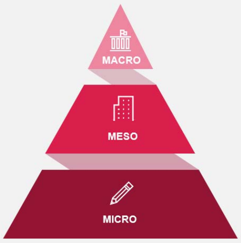
The results of the first online survey of this initiative (conducted in the end of 2018) indicated that the four elements of the AMT-related education and training system that require the most substantial change include **Strategy, Collaboration, Content and Learning Environment**. The second phase of this initiative (January 2018 – December 2019) was devoted to collecting detailed inputs specifically for these four elements. While the analysis aims to cover all eight elements of the framework (including also delivery mechanisms, assessment, recognition, and quality), it has an explicit objective of **identifying key priorities and indicating key directions for action**. To this end, further analysis and the second online survey focussed on the key four elements, and aimed to identify further priorities within each of these four elements.

In the remainder of this chapter, the four top priority elements of the Curriculum Guidelines Framework are presented in more detail. For each of these elements, a set of conceptual principles have been derived. The remaining elements of the framework are also included, but imply a more brief analysis, with an objective to sustain a holistic approach and to highlight the key points of attention for all the elements of the framework.

The guidelines aim to specify, whenever possible, existing tools that could be used for specific elements of the framework. It was, however, not the purpose of the current initiative to develop any new tools. Future initiatives could aim to develop an inventory of all available tools and materials and identify gaps where there would be a need for developing specific new tools. Such exploratory initiatives would be warmly welcomed by stakeholders, as the latter often report a high degree of overlap of projects and initiatives happening at different levels (organisational, regional, country, EU), with many similar tools being developed in parallel with hardly any knowledge of other similar activities.

The guidelines can be translated into the key directions for action for each of the key stakeholder groups (see Figure 1-1) at three distinctive but interconnected levels, namely micro-, meso- and macro, where teachers/trainers and learners form the *micro-level* (classroom); managers of educational and training institutions refer to the *meso-level* (organisation); and policy makers and supporting structures such as, for example, industry associations, cluster organisations and trade unions correspond to the *macro-level* (inter-organisational, national and EU levels). The Highlight below outlines the suggested ways of interpreting the guidelines at each of the abovementioned levels, and specifically highlights the key directions for action per level. The list of the suggested actions, however, is of illustrative nature, and should not be considered exhaustive.

Key directions for action for the relevant stakeholder groups (for each of the curriculum guidelines principles as specified below)



Macro-level: Developing multi-stakeholder initiatives aiming to ensure massive implementation of a specific principle in practice, for example, initiatives aiming to create massive awareness about a specific curriculum guidelines principle; to produce specific tools and materials that would enable its effective implementation; to offer virtual and physical collaboration spaces for exchanging experiences, lessons learned and good practices etc.

Meso-level: Raising awareness about a specific principle within the organisation; embedding it into the strategy at the institutional level; developing operational approach for the implementation of this principle in practice, taking into account specific learners' needs and context.

Change in strategy can happen at three different levels[308], from single improvements to complete transformations:

- Add-on strategy: changes at the level of a single course;
- Integration strategy: changes across many courses, implemented at a more systemic level and also integrated at an institutional level;
- Re-building strategy: fundamental changes in education implying rebuilding the whole curriculum, emerging types of schools.

The add-on strategy and integration strategy are the ones most commonly used, whereas the re-building strategy is at an emerging stage in most engineering education communities[309]. Most engineering schools find it highly challenging to re-build an entire curriculum, so smaller changes are generally preferred. The optimal scale of change depends on the specific context and learners' needs.

Micro-level: Raising awareness about a specific principle among learners (teachers); proactively looking for good practice examples and exchanging experiences with professionals who already practice this principle (teachers); proactively initiating discussions with institutional leaders to consider the opportunities to integrate a specific principle into the curriculum (teachers); proactively integrating a specific principle into own learning trajectory (learners).

The guidelines aim to offer key highlights, indicate a variety of possibilities and identify sources for more detailed information and inspiration. The guidelines by no means aim to serve as a standardised detailed recipe for organising education and training processes, as there is no one best way to approach it. The diversity of learner's needs and contexts per definition implies a need for multitude of approaches, which could also be combined in their own unique/customised education and training solutions. Additionally, while the guidelines aim to primarily address the needs of the manufacturing domain, the identified conceptual principles are likely to be relevant also for other high-tech domains.

5.3. Strategy

Strategy here refers to defining core values, commitments, opportunities, resources and capabilities of an educational and/or training institution with respect to developing

308 Kolmos, A., Hadgraft, R. G., & Holgaard, J. E. (2016) "Response strategies for curriculum change in engineering", International Journal of Technology and Design Education, 26(3), pp. 391-411. doi:10.1007/s10798-015-9319-y
309 *Ibid*.

and implementing a curriculum. Specifically, the elements of strategy include assessing learner's needs, developing curriculum goals and intended learning outcomes.

Having a clear strategy for curriculum development allows for obtaining a better picture of what the desired future should look like, and for shifting from a reactive towards a proactive approach. Strategy creates a higher level of awareness and provides greater focus on activities that will make the curriculum more successful. Strategy defines and drives decisions in curriculum design. Finally, strategy is about making choices. Strategy-related decisions are critical to ensuring that limited resources are being deployed to the most promising opportunities that will provide the greatest return in the future[310].

What should education and training providers keep in mind when developing a strategy for a manufacturing-related curriculum design and development in the new age? Figure 5-2 provides an overview of the conceptual principles that were derived specifically for the Strategy element of the framework. Education and training for the new age require a holistic approach, keeping in mind the bigger picture and fitting into the overall lifelong learning trajectory.

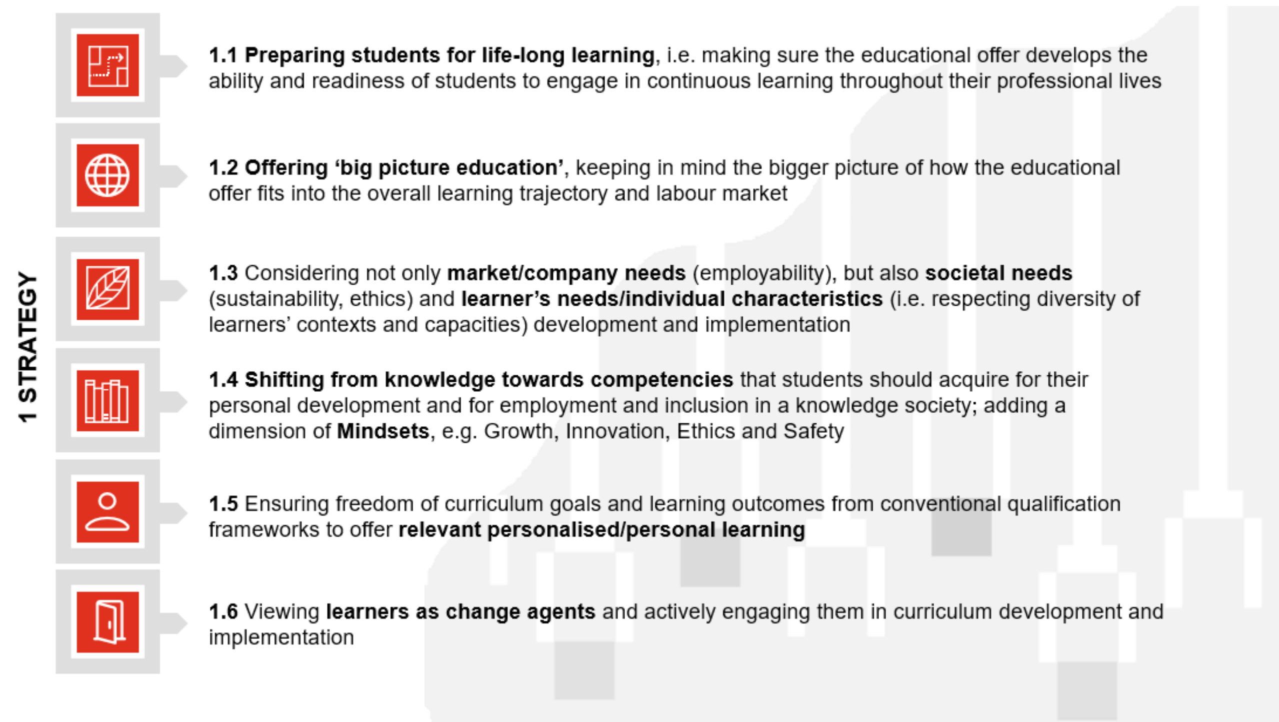


FIGURE 5-2: Six conceptual principles for Strategy

#1.1 Preparing students for life-long learning

Preparing students for life-long learning implies making sure the educational offer develops the ability and readiness of students to engage in continuous learning throughout their professional lives. As renowned futurist Alvin Toffler wrote: "*the*

310 Adapted from AlbuonStrategy (2014) "5 Reasons Why Strategy is Important"

illiterate of the 21st century will not be those who cannot read and write, but those who cannot learn, unlearn and relearn"[311].

The world is going through a workplace revolution that will bring **a fundamental shift in the way humans work alongside machines and algorithms**. The World Economic Forum (WEF) predicts that by 2025, more than a half of all current workplace tasks will be performed by machines as opposed to 29% today. Such a transformation will have a profound effect on the global labour force[312]. At the same time, 133 million new jobs are expected to be created by 2022 compared to 75 million that will be displaced, implying the creation of 58 million net new jobs in the next five years[313].

For industry, it is crucial to support the upskilling of their current workforce towards new and higher-skilled roles, as competition for skilled talent will further intensify and become more costly in the coming years[314]. However, significant upskilling or reskilling will not happen exclusively 'on-the-job'. Experts predict that **workers will have to go back to school at different stages of their career and develop deep expertise in a new domain**. The T-career model (when students go to college in their early twenties and learn on the job for the rest of their life) will be replaced by the **M-career model** (when workers go back to study multiple times in a 40-50-year career) in order to stay relevant[315].

For workers, there is thus a need to take personal responsibility for their learning trajectory and develop **a higher degree of comfort with the concept of lifelong learning**[316]. The latter should be made central in the curriculum development strategy. The curriculum needs to familiarise students with lifelong learning practices and support the development of the lifelong learning mind-set. Specific elements of this mind-set include[317]:

- **Focussing on growth:** continuously exploring one's potential and striving for professional growth;
- **Becoming a multidisciplinary master**: mastering multiple fields of expertise over the lifespan of one's career;
- **Stretching**: moving beyond one's comfort zone, continuously acquiring and practicing new knowledge and skills;
- **Building personal brand and network:** developing and enhancing one's personal brand and building a diverse and large network;

311 Ryan K.J (2016) "4 Things Futurist Alvin Toffler Predicted About Work Back in 1970", Inc.com, 30 June 2016, quoted in Lee Welsh B. (2018) "Education 4.0 — How We Will Learn in the Fourth Industrial Revolution", Medium 18 April 2018
312 WEF (2018) "The Future of Jobs 2018", and Cann O. (2018) "Machines Will Do More Tasks Than Humans by 2025 but Robot Revolution Will Still Create 58 Million Net New Jobs in Next Five Years", published on 17 September 2018
313 *Ibid*.
314 *Ibid*.
315 Van Dam N. (2018) "Lifelong learning will be the bedrock of Industry 4.0", published on changeboard on 14 November 2018
316 Cann O. (2018) "Machines Will Do More Tasks Than Humans by 2025 but Robot Revolution Will Still Create 58 Million Net New Jobs in Next Five Years", published on 17 September 2018
317 Adapted from Van Dam N. (2018) "Lifelong learning will be the bedrock of Industry 4.0", published on changeboard on 14 November 2018

- **Owning personal development:** creating and executing one's learning plans; working with mentors and seeking feedback, measuring progress and making (personal) investments in own development;

- **Doing what one loves**: exploring what gives a person true meaning and purpose in life and play to one's strengths.

The notion of lifelong learning needs to be reflected in the values and attitudes that aim to be promoted by the curriculum, which implies creating awareness among students about the importance and inevitability of lifelong learning, and familiarising them with specific lifelong learning practices. The latter thus implies the need to actually teach/train learners how to engage in lifelong learning. Examples of specific ways to develop lifelong learning skills in learners include the following[318]:

- **Setting learning goals**: learning must have a purpose. To have any value, it must be a meaningful and useful experience. Goal setting is thus one of the lifelong learning skills that strengthens the desire to learn, and learners need to be trained in setting their learning goals.

- **Encouraging learning ownership in learners**: lifelong learning implies the need for learners to take ownership of their learning trajectory and accepting responsibility for their own development. Learners thus need to be given this responsibility as early as possible, starting already from a primary school.

- **Turning learners' mistakes into opportunities**: trying new approaches and experimenting leads to mental and emotional growth; however, it is also inevitably associated with a risk of failure. The latter needs to be transformed into experience and opportunities, which requires having a corresponding culture in the classroom.

- **Providing learners with go-to learning tools**: learners need to be familiarised with a wide variety of learning tools, including both formal and informal sources, such as blogs, fora, chats etc.

- **Let learners teach their knowledge to someone else**: learners need to be engaged to assist and guide their peers, which maximises learning retention.

318 Based on Watanabe-Crockett L. (2019) "6 Ways to Build Lifelong Learning Skills in Your Learners", Wabisabi Learning, 29 October 2019

Highlight 5-1: VET toolkit for tackling early leaving by CEDEFOP[319]

This pan-European toolkit was inspired by successful VET practices in helping young people to attain at least an upper secondary qualification. The toolkit provides practical guidance, tips, good practices and tools drawn from VET to feed into activities and policies aiming at helping young people at risk of becoming early leavers to remain in education and training and qualify; and helping early leavers to reintegrate into education or training and the labour market.

Policy-makers and practitioners, working in ministries, VET schools, companies, guidance centres, public employment services, social services, or youth organisations, can benefit from the toolkit by finding ways to:

- identify and monitor early leavers and learners at risk of leaving education early;
- intervene to retain them in, or bring them back to, education or training;
- evaluate related measures undertaken within a country, region or institution.

The toolkit offers:

- 2 reflection tools, for policy makers and learning providers;
- 2 evaluation plans, for policy makers and learning providers;
- 15 intervention approaches addressing the 8 most common profiles of early leavers;
- 10 protective factors;
- 50+ actively contributing toolkit "ambassadors" from 18 countries.
- 150+ resources of best practices, publications, tools, statistics and quick wins.

In May 2019, Cedefop released the new version of the toolkit:
http://www.cedefop.europa.eu/en/toolkits/vet-toolkit-tackling-early-leaving

#1.2 Offering 'big picture' education

Offering 'big picture' education here implies keeping in mind the bigger picture of how the educational offer fits into the overall learning trajectory and labour market. The approach is closely connected with the term 'Big Picture Learning'. The latter is both a relationship-centred educational model and a global network of schools following that model. It was founded in the United States in 1995 by Dennis Littky and Elliot Washor, with a mission of putting students directly at the center of their own learning[320]. Today, there over 65 Big Picture network schools in the United States, and many more around the world; with schools in Australia, the Netherlands, Italy and Canada utilising the Big Picture Learning design[321].

The **key principles** of Big Picture Learning include the following[322]:

- **Personalisation:** each Big Picture student's learning experience is personalised, both academically and in terms of holistic personal development. Based on their passions and preferences, students work with their educators to decide what and how they will learn and how they will be assessed;
- **Advisory structure:** Each Big Picture student joins an 'advisory', a learning community of around fifteen students. Advisories stay together for four years. Each advisory is led by an 'advisor', a teacher who forms personalised

319 https://www.cedefop.europa.eu/en/toolkits/vet-toolkit-tackling-early-leaving/blog/welcome
320 https://shiftdesign.org/case-study-big-picture-learning/
321 https://www.bigpicture.org/apps/pages/index.jsp?uREC_ID=389353&type=d&pREC_ID=882353
322 https://shiftdesign.org/case-study-big-picture-learning/

relationships with each advisee. Each student's learning experience is determined largely through this collaborative relationship.

- **Learning through interests and internships:** Big Picture Learning is based on a philosophy that the best way engage students is by applying what they learn directly to their own interests. To that end, in Big Picture schools, students often spend up to two days of each week, not in school, but in internships, learning alongside real-world experts in their own communities in a field that they are passionate about.
- **Parent and family engagement:** Parents and families are actively involved in each student's learning process, collaborating on work planning and assessment.
- **School culture:** Big Picture schools are founded on trust and equality between students and adults, with students assuming leadership roles and inputting into school decision-making processes.
- **School organisation:** Big Picture schools do not rely on timetables, bells and assigned buildings. They are instead organised more flexibly, in democratic collaboration with students.
- **Leadership:** Students accept active leadership roles along with staff.
- **Authentic assessment:** Instead of uniform tests, students are assessed according to individualised criteria. These are focused around public displays of learning in particular areas of interest, such as exhibitions or demonstrations (for more information on assessment, please refer to sub-section 5.7.2.).
- **Professional development:** Big Picture Learning offers regular coaching and mentoring sessions to ensure learning in its network schools is personalised and designed to help students plan for the future.
- **Post-secondary planning:** Big Picture students actively develop plans that contribute to their future success – whether through academic work, wider projects, travel or other pursuits.

In traditional education, students graduate upon completion of a mandated number of hours following a prescribed set of courses, especially when it comes to hands-on, skills/competency-based education. Using Big Picture Learning principles, a Competency Education system can be designed where students graduate after they demonstrate mastery of a comprehensive list of competencies (which may also be in the form of learning targets or benchmarks). In this system, learners proceed at their own pace and earn grades relative to whether they exceed, meet or do not demonstrate the competencies being tested. As such, this may also mean learners of different ages may be in the same class for variable amounts of time, and their progress in each competency is both personal and visible at all times, leading to higher motivation and engagement, and reducing stress of "learning within a deadline"[323].

The Big Picture Learning philosophy covers multiple aspects that are addressed by the current guidelines.

#1.3 Addressing not only market, but also societal and learner's needs

When developing curriculum goals, a holistic approach requires considering not only market/company needs (usually referred to as 'employability'), but also societal needs

323 Priest N., Rudenstine A. and Weisstein E. (2012) "Making Mastery Work: A Close-Up View of Competency Education"

(such as sustainability, ethics) and learner's needs or individual characteristics (which implies respecting diversity of learners' contexts and capacities).

Employability is often defined as the ability of graduates to successfully get jobs and to develop in their careers[324], as well as to enable individuals to prove their value to an organisation as the key to job survival[325]. Industry analysts regularly report that for success in the workplace, employees need to possess a specific employability skills entry level requirement. These essential (employability) skills are often viewed as a company's most important raw material[326] and graduates with employability skills are predicted to have an advantage in getting jobs in the industry[327]. Focussing on employability when developing curriculum goals implies putting central the interests of employers. Most institutions in Europe (and worldwide) have responded to these types of requirements by a series of different learning methodologies ranging from internships where students engage in working life early in education to implementation of projects that are carried out with companies[328,329]. Identifying and addressing the current and emerging needs of the industry can be achieved by, for example, **including industrial stakeholders in the governance** of the educational/training institution and by activating processes of **consultation with the industrial stakeholders**[330].

In parallel to the employability agenda, in the last decades, the **sustainability** agenda has also gained popularity. At the academic level, it started in the 70s-80s and gradually turned into official international policies. Today, some countries have formulated learning outcomes within the sustainability domain, for example, the Australian Stage 1 Competency Standard that includes sustainability (Engineers Australia 2011), the Swedish government (Swedish Higher Education Act), and the US ABET criteria 2011–2012[331]. However, in most countries the inclusion of sustainability competencies depends on individual institutions[332].

324 Fugate M., Kinicki A. J. and Ashforth B. E. (2004) "Employability: A psychosocial construct, its dimension, and applications", Journal of Vocational Behavior, 2004, 65(2), pp. 14-38, cited in Rasul M. S. et. al. (2013) "Graduate employability for manufacturing industry", Procedia-Social and Behavioral Sciences, 102, pp. 242-250

325 Askov E. N., Gordon E. E. (1999) "The brave new world of workforce education. New Directions For Adult and Continuing Education", 1999, 83, pp. 59-68, cited in Rasul M. S. et. al. (2013) "Graduate employability for manufacturing industry", Procedia-Social and Behavioral Sciences, 102, pp. 242-250

326 Perry C. (2003) "All employers want the "balanced graduate"", Sydney, Australia: University of New South Wales, Careers and Employment. 2003, cited in Rasul M. S. et. al. (2013) "Graduate employability for manufacturing industry", Procedia-Social and Behavioral Sciences, 102, pp. 242-250

327 Husain, M. Y. et al. (2010) "Importance of Employability Skills from Employers' Perspective", Procedia - Social and Behavioral Sciences, 2010, 7, pp. 430-438, cited in Rasul M. S. et. al. (2013) "Graduate employability for manufacturing industry", Procedia-Social and Behavioral Sciences, 102, pp. 242-250

328 Graham, R. (2010) "UK approaches to engineering project-based learning", White paper sponsored by the Bernard M. Gordon-MIT engineering leadership program, cited in Kolmos, A., Hadgraft R. G., and Holgaard J. E. (2016) "Response strategies for curriculum change in engineering", International Journal of Technology and Design Education, 26(3), 391-411. doi:10.1007/s10798-015-9319-y

329 Royal Academy of Engineering (2007) "Educating engineers for the 21st century", The Royal Academy of Engineering. http://www.raeng.org.uk/publications/reports?p=6, cited in Kolmos, A., Hadgraft R. G., and Holgaard J. E. (2016) "Response strategies for curriculum change in engineering", International Journal of Technology and Design Education, 26(3), 391-411. doi:10.1007/s10798-015-9319-y

330 See, for example, Sistema ITS http://www.sistemaits.it/istituti-tecnici-superiori-its.php

331 Kolmos, A., Hadgraft R. G., and Holgaard J. E. (2016) "Response strategies for curriculum change in engineering", International Journal of Technology and Design Education, 26(3), 391-411. doi:10.1007/s10798-015-9319-y

332 Johnston L. F. (2013) "Higher education for sustainability: Cases, challenges, and opportunities from across the curriculum", New York: Routledge. https://www.dawsonera.com/guard/protected/dawson.jsp?name=https://idp.worc.ac.uk/oala/metadata&dest=http://www.dawsonera.com/depp/reader/protected/ external/AbstractView/S9780203123041 cited in Kolmos, A., Hadgraft R. G., and Holgaard J. E.

In addition to employability and sustainability, the curriculum goals need to take into account the **characteristics of individual learners** in terms of current knowledge, skills, abilities, attitudes and needs. This can be achieved through **self-assessment tools[333], orientation services and co-creation of individual learning paths**. This approach is well aligned with the recommendations of UNESCO-IBE advocating for "*a curriculum that aims to respond to the diversity of expectations and needs of the entire student population*". It requires schools to develop their educational offerings while paying attention to the diversity of students' contexts and capacities. It also requires teachers who are able to organise a learning process that takes into account and respects each person's characteristics and needs[334].

Highlight 5-2: People-centred innovation development approaches[335]

This international project co-funded by the Erasmus+ programme emphasizes that people should become an indispensable part of industrial development processes as a means to achieve practical education as well as new categories of products, services and business strategies that truly address people's needs and lead to sustainable innovation.

Thus the PEOPLE project addresses 3 urgent challenges for the European Union:

- The underemployment of humanities graduates
- The lack of social science expertise in the sustainable living and energy sector
- The need for better-engaged social science learning in higher education

The implementation of people-centred learning cycles brings together interdisciplinary groups of students, educators and industry professionals to solve real-life business challenges – thus addressing immediate practical needs of both graduates and employers while also having long-lasting impact on society at large by improving the relevance of social science teaching and research on contemporary innovation processes.

#1.4 Shifting from knowledge towards competencies

During the last decades, the focus of attention has gradually moved from the access to education and the necessary inputs to the **outcomes of the educational process**. These outcomes are increasingly defined in terms of generic or **cross-cutting competencies** that students should have acquired by the end of their education in order to succeed in their further studies, for their personal development and for employment and inclusion in a knowledge society[336]. Various organisations, including partnerships and consortia, have developed different competency frameworks, defined, among others, as 'key competencies', 'core competencies', 'life skills' or

(2016) "Response strategies for curriculum change in engineering", International Journal of Technology and Design Education, 26(3), 391-411. doi:10.1007/s10798-015-9319-y

333 See, for example, https://www.16personalities.com/

334 UNESCO-IBE (2013) "The Curriculum Debate: Why it is Important Today", IBE Working Papers on Curriculum Issues Nr. 10

335 http://people-project.net/

336 *Ibid*.

'twenty-first century skills' – using different approaches, methodologies and terminologies[337].

It is crucial to have transparency and comparability of competency frameworks across organisations and countries. To achieve this goal, the EU has been investing massive efforts for many years. Highlight 5-3 offers an overview of the key EU frameworks and tools in that respect, that have an objective to ensure fast track integration of the EU citizens into the EU labour market.

Highlight 5-3: EU frameworks and tools for comparability and transparency in education and training: a brief overview[338]

EQF – the European Qualifications Framework[339]

This is the common reference for making qualifications more visible and comparable across different countries and systems. The EQF consists of 8 levels, ranging from the end of compulsory education (Levels 1 to 3) to the highest qualifications such as a Doctorate degree (Level 8). It covers all levels and all subsystems of education and training, focussing on learning outcomes and the person's knowledge, skills and competencies. Qualifications in the EQF are outcomes rather than input based.

NQF – the National Qualifications Framework[340]

Following the adoption of the EQF, the EU invited all member states to adopt a National Qualifications Framework, that is, a description by levels of all qualifications of their national education and training system. Some MS already had their NQF, some did not. In the latter case, MS were called by the EU to develop their own (e.g. Italy). In both cases, MS were called to reference their levels in the NQF to the levels in the EQF. For example, the French NQF has only 5 levels, ordered the other way round compared to the EQF (level 1 is the highest and level 5 the lowest).

ECTS – European Credit Transfer and Accumulation System[341]

The ECTS is a credit system designed to allow students to move between different countries. It especially applies to university, but it can also be used in other education levels. Credits are based on the workload students need to achieve the expected learning outcomes; learning outcomes relate to level descriptors in national and European qualifications frameworks. The workload indicates the time students typically need to complete all learning activities (lectures, seminars, projects, independent study time, etc.) required to achieve a qualification. Credits acquired by passing exams/completing learning activities become "currency" that students can use to navigate between one system of education and another. All relevant ECTS acquired can be added to contribute to an individual's degree programme.

ESG – Standards and guidelines for quality assurance in the European Higher Education Area[342]

The ESG are a set of standards and guidelines for internal and external quality assurance in higher education. The ESG are not standards for quality, nor do they prescribe how the quality

337 http://people-project.net/
338 EfVET – European Forum for technical Vocational Education and Training USRV – Ufficio Scolastico Regionale per il Veneto, I.F.O.A. – Istituto Formazione Operatori Aziendali and Mocci A. (2018) "Identification of policies to improve usage of EU tools in HVET: ECVET, ECTS and ESCO", Intellectual Output 7, PROJECT SHINE: SHare, Improve, develop: today's excelleNce for tomorrow's HVET, February 2018
339 https://ec.europa.eu/ploteus/content/how-does-eqf-work
340 https://www.cedefop.europa.eu/lv/events-and-projects/projects/national-qualifications-framework-nqf
341 https://ec.europa.eu/education/resources-and-tools/european-credit-transfer-and-accumulation-system-ects_en
342 https://enqa.eu/index.php/home/esg/

assurance processes are implemented, but they provide guidance, covering the areas which are vital for successful quality provision and learning environments in higher education. The ESG provide the criteria at European level against which quality assurance agencies and their activities are assessed. This ensures that the quality assurance agencies in the EHEA adhere to the same set of principles and the processes and procedures are modelled to fit the purposes and requirements of their contexts.

ECVET - European Credit System for Vocational Education and Training[343]

The ECVET is the credit system version for Vocational Education and Training (VET), that is, a technical framework to transfer, recognise and accumulate individuals' learning outcomes in order to achieve a qualification. It has some common points with the ECTS: it is a credit accumulation system, it aims at facilitating the recognition of learning outcomes with a view to obtaining a qualification and supporting the mobility of European citizens. At the same time, it is not based on study workload, rather directly on learning outcomes; it encompasses informal and non-formal learning; and it is more labour market-oriented.

EQAVET – European Quality Assurance Reference Framework[344]

The EQAVET is a reference instrument designed to help the EU MS supervise the continuous improvement of their vocational education and training systems based on the commonly agreed references. The EQAVET is meant, by building mutual trust between the VET systems, to make it easier for a country to accept and recognise the skills and competencies acquired by learners in different countries and learning environments. In fact, the EQAVET comprises a quality assurance and improvement cycle (planning, implementation, evaluation/assessment, review/revision) based on a selection of quality criteria, descriptors and indicators applicable to quality management at both VET-system and VET-provider levels.

ESCO – European Skills/Competences, qualifications and Occupations[345]

ESCO is the multilingual classification of Skills, Competences, Qualifications and Occupations relevant for the EU labour market and education and training. Set up in 2017, it is still under development. The Commission developed ESCO as a complementary tool to the EQF. On the one hand, MS develop databases, in which they assign a NQF level to each qualification, relate them to the EQF, and describe the expected learning outcomes. ESCO, on the other hand, offers a standardised terminology to make these learning outcome descriptions understandable and comparable across borders.

In addition to the intended learning outcomes of knowledge and competencies, experts suggest adding to the curriculum a dimension of **Mindsets**. Examples of such Mindsets could be Growth, Employer's perspective, Innovation, Society as the Centre of Engineering, Ethics and Sustainability. Mindsets provide convergence and integration in student learning[346].

#1.5 Offering relevant personalised and personal learning[347]

The current aspect invites to take it a step further and to ensure freedom of curriculum goals and learning outcomes from conventional qualification frameworks to offer **relevant personalised andpersonal learning**.

343 https://ec.europa.eu/education/policy/vocational-policy/ecvet_en
344 https://www.eqavet.eu
345 https://ec.europa.eu/esco/portal/home
346 https://aldertkamp.weblog.tudelft.nl/2017/12/08/over-200-deans-are-thrilled-by-the-futurist-industry-4-0-but-who-has-the-courage-to-adapt-the-curriculum/
347 Based on PwC (2019) "Promoting Online Training Opportunities for the Workforce in Europe", Final Report, prepared for DG GROW/EASME of the European Commission, October 2019

The learning field is moving into the direction of creating "**Learning Engagement Systems**", i.e. solutions that use profile data about learners, their personalities, their habits, goals and feedback from others. The objective is to drive personalised learning and provide coaching and connections to help keep learners connected with their ambitions and their personal development priorities (enabled by AI)[348].

The objective is to accelerate learning by tailoring the instructional environment (i.e. what, when, how, and where students and workers learn) and addressing the individual needs, skills and interests of each student to ensure authentic comprehension. Learners take ownership of their learning, while also developing personal connections with each other, their teachers and other adults. Learning is tailored to each student's unique strengths, thereby encouraging curiosity while keeping them engaged and present[349].

As specified in sub-section 3.3.2., a distinction needs to be emphasised between **personalised and personal learning**. In case of personal learning, the control shifts from the teacher/instructor to the learner, with personal learning representing a culture and a mindset[350]. However, this may not always be an optimal approach in a workplace learning setting. Employers may need their employees in specific job roles to learn specific skills to do their job better. A possible solution here could be to give employees an option to pick up a course of their choice when the employee completes a specific number of courses or modules, which are linked directly to their day-to-day job role[351].

Personal learning and personalised learning are two different approaches to learning. There is no one-size fits all approach for choosing an ideal learning strategy. Personalised learning powered by adaptive learning techniques and data-driven systems may lead to better-optimised and easier-to-control solutions for workplace learning. At the same time, personal learning promises to cultivate genuine interest in learning and thus is likely to lead to a higher impact of learning activities. The choice for the appropriate approach depends on a wide variety of factors including specific learning needs and objectives, available budgets and motivations. As highlighted above, both approaches can also coexist next to each other.

#1.6 Viewing learners as change agents

Finally, defining curriculum strategy for the new age implies viewing learners as change agents and actively engaging them in curriculum development and implementation. This approach allows for considerably advancing student experience. Possible forms of student engagement include the following[352]:

- **Consultation**: it is typically carried out by means of surveys or focus groups. They are likely to reach high numbers of learners, leading to large datasets and are relatively quick and cost effective. However, the specificity of the questions limits the depth of analysis and can be skewed by the point in time at which the consultation takes place.

348 Fosway Group (2017) "Digital Learning Realities 2017: Part 1 -Organisation, Headcount, Budget and Investment", in association with learning technologies, May 2017

349 Lee Welsh B. (2018) "Education 4.0 — How We Will Learn in the Fourth Industrial Revolution", Medium 18 April 2018

350 https://modernlearners.com/learning-is-personal-not-personalized/

351 Origin Learning (2018) "The Personal Versus Personalized Learning Debate", published on 19 July 2018

352 Mutton J., Foyle C. (2017) "Students as change agents"

- **Collaboration**: usually it involves learners in improving existing processes or projects; for example, they may be asked to join a project board or participate in a periodic review. This allows learners to influence processes that have a direct impact on them. However, it can be difficult to engage learners in an already established project and the amount of influence they might have can be limited.
- **Co-production**: it is a way of engaging learners as equals, where they define the terms of their engagement and the role they are playing, leading to a deeper understanding of the student experience. Co-production also develops a sense of belonging in learners, which, in turn, can impact on retention and attainment. Possible innovative ways of engaging with learners include video diaries, shadowing, storyboarding and prototyping. Often, the process or project needs to be redefined from the student's perspective and the service aim needs to be fundamentally changed.

The abovementioned approach is closely related to the key principles of Big Picture Learning that was mentioned earlier in this sub-section. Several new universities that are built 'from scratch' with completely new curricula, as well as forward-thinking schools of engineering already do engage learners in curriculum development and implementation, thereby contributing to the cultivation of the new generation of learners as the change agents[353].

Other remarks related to Strategy

Change in strategy can happen at three different levels, ranging from single improvements to complete transformations[354]:

- **Add-on strategy**: implies changes at the level of a single course;
- **Integration strategy**: implies changes across many courses, implemented at a more systemic level and also integrated at an institutional level; *and*
- **Re-building strategy**: implies fundamental changes in education related to rebuilding the whole curriculum, more relevant for the emerging types of schools.

The add-on strategy and the integration strategy are the ones most commonly used, whereas the re-building strategy is at an emerging stage in most engineering education communities. Most engineering schools find it highly challenging to re-build an entire curriculum, so smaller changes are generally preferred[355].

The final remark here refers to the **identifying and measuring intended learning outcomes.** Once curriculum goals have been developed and embedded in educational/training offers, it is also necessary to identify metrics for success and track these metrics dutifully[356]. In other words, it is necessary to verify if the learnings are indeed helping to achieve the short-term and long-term goals, for both individuals

353 Kamp. A (2016) "Engineering Education in the Rapidly Changing World: Rethinking the Vision for Higher Engineering Education", 2nd revised edition, Delft University of Technology and 4TU.Centre for Engineering Education

354 Kolmos, A., Hadgraft R. G., and Holgaard J. E. (2016) "Response strategies for curriculum change in engineering", International Journal of Technology and Design Education, 26(3), 391-411. doi:10.1007/s10798-015-9319-y

355 *Ibid*.

356 https://core.ac.uk/download/pdf/4152582.pdf

and companies. Since no one metric can comprehensively signal successful outcomes, a **holistic combination of metrics** is highly recommended, including, among others, metrics such as:

- employee satisfaction and sense of recognition;
- employee retention rate and competence level over time;
- number of workers trained per year;
- number and degree of (new) skillsets and expertise in the company;
- investment in training and estimated ROI/payback period;
- productivity and efficiency increase;
- number of innovation initiatives pursued per year;
- customer/client satisfaction etc.

For more information on assessment and recognition, please refer to sub-sections 5.7.2. and 5.7.3.

5.4. Collaboration

Collaboration refers to connecting individuals and institutions by facilitating the exchange of practices and resources with a view to improve the educational offer.

Moving towards a paradigm of lifelong learning, educational institutions also need to evolve and occupy new roles in the ecosystem. The infrastructure of educational institutions can be used for experiencing learning and teamwork to enable collaboration, going beyond just flipping classrooms, with hands-on experience, stimulation of critical thinking and real-world projects, where industry meets education. Schools and universities in the New Industrial Age should serve as collaboration spaces and innovation centers.

The abovementioned developments imply **the evolution of existing and the emergence of new collaboration patterns**. These changes may occur within institutions and between institutions. While many lifelong learning departments are being created, there is an increasing need to intimately connect and integrate them with existing faculties and departments within their mother-organisation[357]. Aligning expectations, motivations and vision across departments in this way will not only enhance the quality and recognition of educational offerings, but also create a more enriching environment for teaching and learning. There may also be (private-public) partnerships between educational institutions alongside closer relations with private sector companies. Early pilots show that private-public partnerships between companies and educational institutions can help fill the skills gap and create confident employees[358]. Moreover, educational institutions are also exploring partnerships to share expertise with a view to closely match the needs of regional economies (e.g. FITech Network University concept[359]).

Different types of collaboration are needed, **to ensure a multitude of experiential opportunities**, including collaboration with companies (i.e. manufacturers, technology providers, start-ups), other educational institutions (via joint platforms, thematic networks etc.), peers (peer-to-peer learning), supporting structures (e.g.

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357 https://evolllution.com/managing-institution/internal_service_partnerships/benefits-and-challenges-in-partnerships-between-continuing-education-and-faculties/

358 https://trainingindustry.com/articles/workforce-development/partnerships-with-educational-institutions-help-to-fill-skill-gaps-and-create-confident-employees/

359 https://fitech.io/fitech/

industry associations, cluster organisations and similar), governments, community and the evolving breed of human counterparts, machines. Figure 5-3 provides an overview of the conceptual principles that were derived specifically for the Collaboration element of the framework.

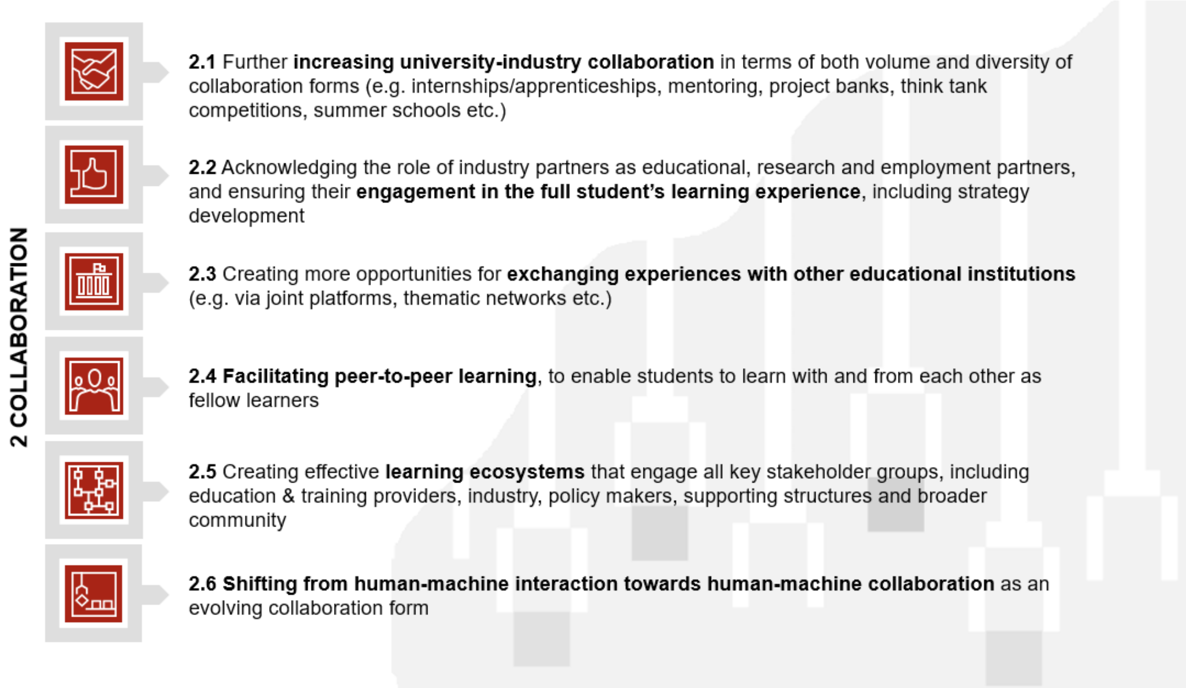

FIGURE 5-3: Six conceptual principles for Collaboration

#2.1 Increasing university-industry collaboration

The current principle implies further increasing university-industry collaboration in terms of both volume and diversity of collaboration forms.

Finding solutions to technical, social, environmental and economic challenges increasingly requires collaboration between universities and industry, as only few organisations have an internal capacity to deliver results on their own[360]. University-industry collaboration can take place in **many forms** including, among others, internships and apprenticeships, funding undergraduate scholarships and graduate research fellowships, funding research, student mentoring, partnering in a campus research center or institute to help steer technology development, participation in informational career events for students, project banks, think tank competitions, summer schools etc.[361]. University-industry collaboration can bring multiple mutual benefits, as the collaboration results can flow out to industry, and they can also feed science[362].

360 Gann D. et al. (2018) "3 ways to nurture collaboration between universities and industry", World Economic Forum, 23 November 2018, /
361 Giges N. (2018) "Academia and Industry Partnerships Go Far Beyond Internships", ASME.org published on 20 June 2018
362 Gann D. et al. (2018) "3 ways to nurture collaboration between universities and industry", World Economic Forum, 23 November 2018

While collaborations with manufacturers and technology providers in general can bring benefits to all sides, enabling each to gain from the expertise of the other, **collaborating with startups** can be particularly valuable[363]. Startups typically are more agile and open to untested approaches, which provides unique opportunities to start down the path toward innovation or deeper explore an already-initiated technical challenge[364]. Collaboration of universities with startups can play a crucial role in offering some unique and diverse solutions that help define the developments of the new age.

Existing research suggests that the following factors determine the success of industry-university collaboration[365]:

- **Flexibility**: it implies being flexible regarding one's own priorities since the collaboration partner might have others[366], to adopt formal rules where necessary and to compromise where appropriate[367], as well as to be open-minded and to seize chances[368,369]. Furthermore, it is important to understand and accept cultural differences, and not to impose one's own convictions and approaches on the partner[370,371]. It has also been shown to be beneficial to create collective goals to be able share the same visions and interests[372]. To summarise, management processes need to be flexible enough to cope with uncertainty and change[373], as well as with the diverse interests of the partners.

- **Trust**: building trust implies treating the partner fairly, communicating openly and without delay[374]. Transparency and openness is also crucial regarding goals, IPR policies and knowledge transfer[375,376]. Trust plays a vital role when it comes to the exchange of knowledge.

- **Clarity**: it implies having clear aims, planning as realistically as possible, agreeing on responsibilities, specifying the extent of the contribution of each

363 Tidhar E. et al. (2018) "Toward the next horizon of Industry 4.0: Building capabilities through collaborations and startups", Deloitte on 1 August 2018
364 *Ibid.*
365 From Rybnicek R. and Königsgruber R. (2019) "What makes industry–university collaboration succeed? A systematic review of the literature", Journal of Business Economics, March 2019, Volume 89, Issue 2, pp. 221–250
366 Poston R.S., Richardson S.M. (2011) "Designing an academic project management program: a collaboration between a university and a PMI chapter", Journal of Information Systems Education 22 pp. 55–72
367 Muscio A, Vallanti G. (2014) "Perceived obstacles to university–industry collaboration: results from a qualitative survey of Italian academic departments", Industry and Innovation, 21, pp. 410–429
368 Barnes T., Pashby I., Gibbons A. (2002) "Effective university–industry interaction: a multi-case evaluation of collaborative R&D projects", European Management Journal 20, pp. 272–285
369 Ryan L. (2007) "Developing a qualitative understanding of university-corporate education partnerships", Management Decision 45, pp. 153–160
370 Barnes T., Pashby I., Gibbons A. (2002) "Effective university–industry interaction: a multi-case evaluation of collaborative R&D projects", European Management Journal 20, pp. 272–285
371 Starbuck E. (2001) "Optimizing university research collaborations", Research Technology Management 44, pp. 40–44
372 Hong W, Su Y-S (2013) "The effect of institutional proximity in non-local university–industry collaborations: an analysis based on Chinese patent data", Research Policy 42, pp. 454–464
373 Barnes T., Pashby I., Gibbons A. (2002) "Effective university–industry interaction: a multi-case evaluation of collaborative R&D projects", European Management Journal 20, pp. 272–285
374 *Ibid.*
375 Bstieler L., Hemmert M., Barczak G. (2015) "Trust formation in university-industry collaborations in the US biotechnology industry: IP policies, shared governance, and champions", Journal of Product Innovation Management 32, pp. 111–121
376 Santoro M.D., Bierly P.E. (2006) "Facilitators of knowledge transfer in university-industry collaborations: A knowledge-based perspective", IEEE Transactions on Engineering Management 53, pp. 495–507

partner and defining roles right at the beginning[377,378]. It is also crucial to be clear about expectations[379] regarding IPR policies[380], ownership and patent earnings[381,382] and about the exploitation of project results[383]. It is essential to take enough time to understand the partner's interests, to ask questions, to discuss purposes and visions and eventually to negotiate these[384,385]. Concrete agreements and contractual safeguards are likely to be helpful in this regard[386]. To summarise, in the long term, a collaboration is more likely to succeed if the main points are clarified between the partners in the beginning.

- **Awareness**: awareness here refers to the knowledge of the current economic, legal, political or social developments. These developments are likely to have a considerable impact on collaboration and therefore should be neither underestimated nor neglected. It implies keeping up to date with them and being aware of their influence on companies and universities (e.g. observing and exploiting opportunities for public funding or watching out for the possibility of (tax) incentives). Furthermore, it includes monitoring changes in the market environment[387] and being aware of corporate instability[388]. Finally, it also means analysing the wealth, the innovation intensity or the employment market of a region[389].

University-industry collaboration can take physical and/or virtual form. For the latter, **online platforms for collaboration with industrial partners** become increasingly popular. Such platforms often include areas dedicated to communication between faculty members and industry representatives, as well as a service that matches students and faculty with industry projects (project banks), instructional content and more[390].

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377 Barnes T., Pashby I., Gibbons A. (2002) "Effective university–industry interaction: a multi-case evaluation of collaborative R&D projects", European Management Journal 20, pp. 272–285

378 Franco M., Haase H. (2015) "University–industry cooperation: researchers' motivations and interaction channels", Journal of Engineering and Technology Management 36, pp. 41–51

379 Barnes T., Pashby I., Gibbons A. (2002) "Effective university–industry interaction: a multi-case evaluation of collaborative R&D projects", European Management Journal 20, pp. 272–285

380 Starbuck E. (2001) "Optimizing university research collaborations", Research Technology Management 44, pp. 40–44

381 Barnes T., Pashby I., Gibbons A. (2002) "Effective university–industry interaction: a multi-case evaluation of collaborative R&D projects", European Management Journal 20, pp. 272–285

382 Bruneel J., D'Este P., Salter A. (2010) "Investigating the factors that diminish the barriers to university–industry collaboration", Research Policy 39, pp. 858–868

383 Newberg J.A., Dunn R.L. (2002) "Keeping secrets in the campus lab: law, values and rules of engagement for industry–university R&D partnerships", American Business Law Journal, 39, pp. 187–240

384 Borgia D., Bonvillian G., Rubens A. (2011) "Case study of Chinese and US University, college of business partnerships: form, process, opportunities, and challenges", Journal of Management Policy Practice 12, pp. 98–107

385 Ryan L. (2009) "Exploring the growing phenomenon of university-corporate education partnerships", Management Decision 47, pp. 1313–1322

386 Hemmert M., Bstieler L., Okamuro H. (2014) "Bridging the cultural divide: trust formation in university–industry research collaborations in the US, Japan, and South Korea", Technovation 34, pp. 605–616

387 Hadjimanolis A. (2006) "A case study of SME-university research collaboration in the context of a small peripheral country (Cyprus)", International Journal of Innovation Management 10, pp. 65–88

388 Barnes T., Pashby I., Gibbons A. (2002) "Effective university–industry interaction: a multi-case evaluation of collaborative R&D projects", European Management Journal 20, pp. 272–285

389 Berbegal-Mirabent J., Sánchez García J.L., Ribeiro-Soriano D.E. (2015) "University–industry partnerships for the provision of R&D services", Journal of Business Research 68, pp. 1407–1413

390 GEDC (2017) "GEDC Industry Forum 2017: Designing the Future of Engineering Education", Industry Forum Report

Highlight 5-4: Virtual Learning Factory Toolkit[391]

Within the context of the Management Engineering Masters course offered by Politecnico di Milano, there is an action-based learning module called Smart Manufacturing Lab where students are challenged to start from a real world industrial case, define a set of engineering problems faced by real manufacturing companies and subsequently address them in multidisciplinary ways. Students spend time within research laboratories but also on the factory floor of the companies, thus solving problems within a. "learning factory".

As an evolution of this programme, a new Erasmus+ initiative involving faculty from multiple universities across Europe will participate in developing and integrating a Virtual Learning Factory Toolkit – a set of digital tools to support advanced engineering education in manufacturing.

#2.2 Engaging industry in full student's learning experience

There is a need to acknowledge the role of industry partners as educational, research and employment partners, and to ensure their engagement in the full student's learning experience, including strategy development. All these activities become part of the **hiring process in the new age**. It is no longer about a company showing up at a career fair to interview graduate students. Instead, both parties have a much longer time to get to know each other and decide whether it is a good fit[392]. It signifies a **holistic approach** that starts from considering what companies might need either as an immediate need or a pipeline need, followed by a conversation about how companies can positively influence the educational process, and all the way up to the actual hiring of graduates. This approach benefits students as it allows for the integration of all the components, including what they learn in the classroom and knowledge of industry needs and developments[393].

#2.3 Exchanging experiences with other educational institutions

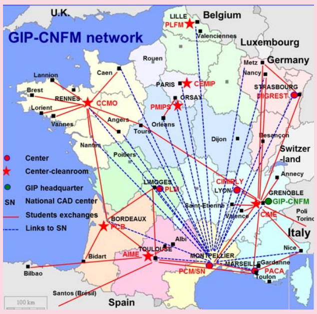
When it comes to reshaping curricula, education and training providers often have to deal with similar challenges and go through the same processes. Multiple activities take place in parallel in different organisations. While one school or university is trying to solve a certain issue, a dozen of others may have already faced this issue too and possibly even found a solution. Therefore, there is a clear need to create more opportunities for **exchanging experiences with other educational institutions, to build on synergies and minimise redundancies of efforts**. Such exchanges can be organised in different forms, both physically and virtually, for example, via joint platforms, thematic networks etc.

391 https://www4.ceda.polimi.it/manifesti/manifesti/controller/ricerche/RicercaPerDocentiPublic.do?EVN_PRODOTTI=evento&lang=EN&k_doc=166149&aa=2019&n_docente=marcello&tab_ricerca=1&jaf_currentWFID=main

392 Giges N. (2018) "Academia and Industry Partnerships Go Far Beyond Internships", ASME.org published on 20 June 2018

393 *Ibid*.

Highlight 5-5: GIP-CNFM network (National coordination for Education in Microelectronics and Nanotechnologies, France)[394]



The essence of the GIP-CNFM network is to share platforms due to high equipment and operating costs, but also to share pedagogical approaches and good practices. Collaboration within the network exists in several forms: on the one hand, through the sharing and common use of technological and design platforms, and on the other hand, through collaborative work in the context of national, or international, multi-year projects and through the organisation of steering committees, national pedagogical days and reflection seminars, particularly within the framework of the network's Orientation Council. These joint activities allow for the exchange of knowledge and practices in order to produce and disseminate knowledge and know-how to the entire academic community. This good practice is atypical within the French academic world and serves as an example for other fields both in France and abroad. The use of platforms shared by several academic institutions allows users from different backgrounds belonging to different institutions to meet and collaborate while acquiring know-how that is essential for all.

#2.4 Facilitating peer-to-peer learning

Peer-to-peer learning represents a method of learning in which **students and workers learn from and with each other**. This approach allows for developing new opportunities and connections between the peers, and leads to more learning. The latter happens due to the fact that learners explain their ideas to others and participate in activities in which they can learn from their peers. As a result, they develop management and planning skills, as well as skills related to teamwork and presentation, feedback and evaluation[395]. Furthermore, the approach also fosters the development of own opinion and tolerates subjectivity of opinions, as peers are encouraged to share their own ideas, thoughts and views on a certain subject.

Schools[396] and universities increasingly start using various forms of peer, collaborative or cooperative learning in specific courses, to assist students to meet various learning outcomes. The latter include working collaboratively with others, taking responsibility for their own learning and deepening their understanding of specific content. Evidence is growing that peer learning creates greater confidence and independence in learning, and leads to deeper understanding and improved grades for both peer leaders and their students[397].

Peer-to-peer learning at universities and at the workplace can be facilitated by the use of **collaboration tools and platforms**. While many of these platforms were not explicitly designed for learning, they provide a shared platform for peers (students or employees) to engage with each other. These platforms typically offer discussion

394 Bonnaud O. (2018) "The CNFM education action and its connection with the ACSIEL, French industrial union of semiconductor: Increasing the quality and relevance of existing curricula", CNFM (France), Presentation at the third expert workshop in Brussels on 13 December 2018
395 Peersdom (2014) "Benefits of Peer-to-Peer Learning", Peersdom 12 February 2014
396 See, for example, the "19" Coding School in Brussels, Belgium: https://www.s19.be/the-school-19/
397 *Ibid*.

rooms, virtual workspaces, private chats along with the performance support, all of which are examples of facilitating peer-to-peer learning[398].

For example, email and LinkedIn now share space with Slack, Jive, Yammer etc. All of these technologies allow teams and individuals within organisations to quickly share work-relevant information with each other. These platforms can thus host powerful peer learning feedback loops, and also develop the collaboration-focused soft skills that are essential for the 21st Century workers to solve complex open-ended problems. However, the ability to use these technologies well is not innate, and benefits from a guided introduction to use them effectively in real-world project-centric contexts[399].

#2.5 Creating effective learning ecosystems

There is a need for creating effective **learning ecosystems**, engaging all key stakeholder groups. Such learning ecosystems need to cater the specific needs of individuals, groups, enterprises, value chains and clusters. Training developers need to form a prominent part of these ecosystems, building on close collaboration with all other key stakeholder groups, with a central role assigned to learners themselves. Such learning ecosystems could benefit from the offer of the centralised platforms, but would not be limited to those.

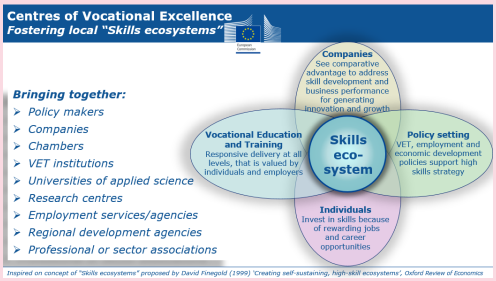
AI-augmented learning ecosystems and platforms need to facilitate access of learners to relevant personalised and personal learning solutions from any suitable possible sources. They would also need to include guidance, coaching, assistance, assessment, validation and certification of learning outcomes with developing personalised and personal learning and career paths in connection with attractive job opportunities during the whole professional career[400].

398 Learningcrafters (2019) “How to Enable Peer-to-peer Learning in Corporate Environment?”, 20 March 2019

399 https://vov.be/inspiratie/4-diy-tips-for-creating-a-knowledge-sharing-culture-door-matthias-nauwelaers

400 PwC (2019) “Promoting Online Training Opportunities for the Workforce in Europe”, Final Report

Highlight 5-6: Centres of Vocational Excellence (CoVE)[401]



The "Centres of Vocational Excellence" is a new initiative of the European Commission, aimed at adopting a systemic approach through which trans-national platforms of VET institutions actively contribute to co-create "**skills ecosystems**", together with a wide range of local/regional partners. The latter refer to the initial and continuing VET providers, tertiary education institutions including universities of applied sciences and polytechnics, research institutions, science parks, companies, chambers and their associations, social partners, sectoral skills councils, professional/sector associations, national and regional authorities and development agencies, public employment services, etc.

This initiative supports the establishment of CoVE's that operate in a given local context, through transnational cooperation platforms that:

- bring CoVE's that share a common interest in **specific sectors** or trades (e.g. aeronautics, e-mobility, green technologies, ICT, healthcare, tourism, etc.), or
- develop innovative approaches to **tackle societal, technological and economic challenges** (e.g. integration of migrants, Digitalisation, Artificial Intelligence, Sustainable Development Goals, upskilling people with skills and/or low qualification levels, etc.).

#2.6 Shifting from human-machine interaction towards human-machine collaboration

Human-machine collaboration becomes paramount for organisations. Having the right mindset for AI means being at ease with the concept of '**human *and* machine'**, leaving the mindset of 'human vs. machine' behind[402]. As highlighted throughout the report, this is an age of change and this change happens fast. Those able to understand that the future includes living, working, co-existing, and collaborating with AI-enabled machines are set to succeed in the coming years. On the other hand, those who neglect the fact that digital transformation increasingly relies on human-machine collaboration, will be inevitably left behind[403]. This aspect therefore needs to get a prominent place in the curriculum.

The following **eight fusion skills** will need to be developed for a successful human-machine collaboration at the workplace[404]:

401 Santos J. (2019) "Collaborative platforms for Vocational Excellence: Co-creating skills ecosystems responsive to future skill needs", DG EMPL of the European Commission (Belgium), Presentation at the sixth expert workshop in Brussels on 17 September 2019

402 Fourtané S. (2019) "Human + Machine Collaboration: Work in the Age of Artificial Intelligence", Interesting Engineering, 28 September 2019

403 *Ibid*.

404 From Daugherty P.R. and Wilson H.J. (2019) "Human + Machine: Reimagining Work in the Age of AI", 20 March 2018, cited in Fourtané S. (2019) "Human + Machine Collaboration: Work in the Age of Artificial Intelligence", Interesting Engineering, 28 September 2019

- **Rehumanising time**: humans will have to allocate more time to more 'human' activities, such as increasing interpersonal interactions and creativity;

- **Responsible normalising**: there is a need to normalise the purpose and perception of human-machine collaboration with regard to individuals, businesses, and society as a whole;

- **Judgment integration**: a machine may be uncertain about something or lack the necessary business or ethical context to make decisions. In this case, humans have to be prepared to sense where, how, and when to step in and provide input;

- **Intelligent interrogation**: humans can hardly probe massively complex systems or predict interactions between complex layers of data on their own. They need to acquire the ability to ask machines the 'right' smart questions across multiple levels;

- **Bot-based empowerment**: a variety of bots are available to help humans be more productive and become better at their jobs. Using the power of machines can extend human's capabilities, reinvent business processes, and even boost a human's professional career;

- **Holistic (physical and mental) melding**: the full reimagination of business processes can only be possible when humans create working mental models of how machines work and learn, and when machines capture user-behavior data to update their interactions;

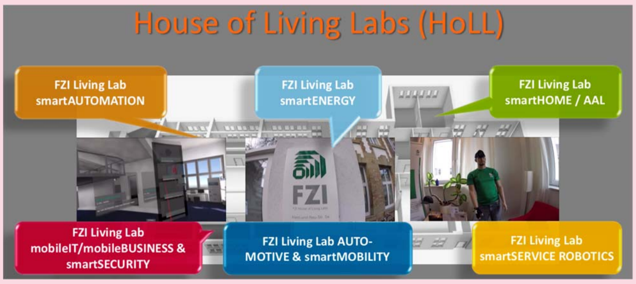
- **Reciprocal apprenticing**: in the past, technological education implied that humans learned how to use machines. With AI, machines are learning from humans, and humans, in turn, learn from machines. In the future, humans will perform tasks together with the AI agents to learn new skills, and will receive on-the-job training to work well within AI-enhanced processes; *and*

- **Relentless reimagining**: this hybrid skill implies the ability to reimagine the current situation, and to keep reimagining how AI can transform and improve work, organisational processes, business models, and even entire industries.

Human-machine collaboration implies a **continuous circle of learning**, a constant exchange of knowledge between humans and machines[405], and the workforce needs to be prepared for this emerging type of collaboration.

405 Daugherty P.R. and Wilson H.J. (2019) "Human + Machine: Reimagining Work in the Age of AI", 20 March 2018, cited in Fourtané S. (2019) "Human + Machine Collaboration: Work in the Age of Artificial Intelligence", Interesting Engineering, 28 September 2019

Highlight 5-7: Making analytics come alive with Digital Twins[406]



At the Forschungzentrum Informatik (FZI), there are a host of living labs that create sandboxes for experiments with IoT, analytics and visualisations in simulations resembling real-world conditions. Digital Twin technology is one of the applications being developed wherein digital information and physical assets can be bridged as one unified entity, perceived and managed in real-time using a combination of technologies from data analytics to augmented reality, allowing humans to intuitively interface with systems in real-time. Mainstream applications of Digital Twins are as yet rare, since this technique is still in its infancy, though it could eventually represent a new frontier in productivity and innovation in the near-future.

Other remarks related to Collaboration

Adult learners typically have different needs, motivations and learning styles compared to students[407]. The learning environment and method of pedagogy has to be designed differently, with a heavy emphasis on engaging learners' intrinsic motivations and collaborating with them on planning their leaning outcomes[408]. It is also necessary to acknowledge the emotional aspects of learning, which can be accommodated within a social and collaborative learning environment[409]. Contrary to traditional one-way pedagogy, it is increasingly a possibility to **engage communities of practice** as knowledge-sharing networks[410]. Furthermore, educators are increasingly realising that adult education not only benefits the individual and their employer, but also the communities in which they work and serve[411]. Thus highlighting the social and societal angle may also serve to engage and motivate a larger group of adult learners.

5.5. Content

The Content dimension here refers to the nature of educational content and includes specific conceptual principles related to the actual content of the curricula, i.e. syllabus. Education and training providers need to teach the curriculum of the future, not the past[412]. Figure 5-4 provides an overview of the conceptual principles that were derived from the analysis.

406 https://www.fzi.de/en/research/fzi-house-of-living-labs/
407 https://www.ryerson.ca/content/dam/lt/resources/handouts/EngagingAdultLearners.pdf
408 http://northernc.on.ca/leid/docs/engagingadultlearners.pdf
409 https://www.newvisions.org/blog/entry/social-emotional-learning-and-adult-learning-connecting-the-dots
410 https://sloanreview.mit.edu/article/designing-effective-knowledge-networks/?fbclid=IwAR2AO0cgKWdKJ-GAJrDaOylwm_FVbCiGbenZVnA3_yxcJwZxjCntG-gURmU
411 https://www.wea.org.uk/sites/default/files/WEA_Impact_Report_2017_0502.pdf
412 Partovi H. (2018) "Why schools should teach the curriculum of the future, not the past", WEF 17 September 2018

FIGURE 5-4: Six conceptual principles for Content

A well-designed syllabus serves multiple functions such as providing a skeleton for theory and activities, preparing a student for the scope and context of the learning, defining students' and teachers' roles, and managing expectations by setting clear learning outcomes[413]. Syllabus design includes defining aspects such as location and schedule of the course, learning objectives and required materials, requirements such as prior certifications and attendance, and importantly how the student's learning will be assessed.

The way the content is delivered may vary depending on the topic, the audience and the desired learning outcomes[414,415]. For example, for some groups, a theoretical course may not be well suited. Similarly, if the desired learning outcome is to change habits or behaviour, it may be necessary to eschew book learning for a more practice-oriented session. Thus, various approaches and techniques need to be explored to diffuse the necessary knowledge to the right audience in the most effective way possible.

Some examples[416] of innovations in adult learning syllabus design include case studies and experience-sharing, (serious) games and scenario-based role playing, projects and group assignments, creative workshops and hands-on training with new technologies like 3D printing, learning analytics to track and personalise effective

413 https://acert.hunter.cuny.edu/blog/syllabus-design/2015/07/30/
414 https://www.trainingzone.co.uk/community/blogs/markben/best-delivery-methods-for-adult-training
415 https://www.clearhorizon.com.au/all-blog-posts/adult-learning-principles-and-styles-areas-to-consider-when-delivering-training.aspx
416 https://www.trainingzone.co.uk/community/blogs/markben/best-delivery-methods-for-adult-training

learning outcomes. The reader is also advised to explore the 4C/ID model[417] and the First Principles of Instruction[418].

#3.1 Upgrading the technical side of the curriculum

From a technical point of view, students and workers need to be adequately trained in the basics of AMT – how they work, how to use them in the right way, how to monitor, assess and maintain their performance, how to combine multiple AMTs and how to evolve AMT based of observations and insights. In other words, learners need to develop a deep sense of familiarity with AMT, and understand its benefits and limitations at an intuitive level[419].

Leading-edge manufacturing technologies are hardly present in today's engineering curricula[420]. Bachelor and Master curricula in any engineering discipline need to be upgraded to include the learning of[421]:

- **Applications**:
  - e.g. Digital Factory
- **Technologies**:
  - Next-generation robotics;
  - Additive manufacturing;
  - Smart materials;
  - Artificial Intelligence and machine learning;
  - Internet of Things (IoT);
  - Augmented and Virtual reality technologies;
  - Predictive analytics;
  - Data science, data analytics, cybersecurity
- **Specialties**:
  - Analog/digital electronics;
  - Signal processing;
  - Sensors;
  - Embedded electronics etc.

The curricula should also contain the basic knowledge and associated know-how in the following specialities: analogue and digital electronics, signal processing, sensors and actuators, embedded electronics, energy harvesting systems, communications, transmission protocols and human-machine communication systems (vision, sound, touch, etc.). These specialities must meet the **future requirements of a connected society**, namely low power, speed, reliability, low cost[422].

417 Van Merrienboer J. (2002) "Blueprints for complex learning: The 4C/ID-model", Educational Technology Research and Development, June 2002,
418 Merrill D. (2002) "First Principles of Instruction", Educational Technology, Research and Development; 2002; 50, 3
419 https://e-colorado.coworkforce.com/File.aspx?ID=45618
420 Kamp. A (2016) "Engineering Education in the Rapidly Changing World: Rethinking the Vision for Higher Engineering Education", 2nd revised edition, Delft University of Technology and 4TU.Centre for Engineering Education
421 *Ibid*.
422 Stakeholder inputs

Basic knowledge of computer sciences will be essential for mechanical, electrical, and electronic engineering in future[423]. At the same time, computer sciences also need mechanical, electrical, and electronic engineering in connection with Industry 4.0. This demands a stronger interdisciplinary approach towards the content of study programs and improved collaboration between the individual departments and faculties. A promising approach here refers to the introduction of a two-semester **joint core curriculum in engineering sciences**, giving students equal insight into the disciplines of mechanical, electrical, and electronic engineering, as well as computer sciences. It could also provide a stronger basis for students for deciding on a core discipline to concentrate on later. When it comes to developing the content of the curriculum, companies should be closely engaged. Such a joint core curriculum, adapted to the needs of Industry 4.0, would connect the worlds and ways of thinking in engineering sciences from the very beginning[424].

Finally, engineers of the new age specifically require expertise and capabilities in **data analytics,** including control and manipulation of big and small data through algorithms, programmes and scripts, cybersecurity, cloud computing and optimisation techniques in design, engineering and research. Future engineers will therefore have to be data literate, i.e. have a good working knowledge of and skill in algorithmic thinking and programming, statistics, domain knowledge and data visualisation techniques in order to operate successfully in an increasingly "data–rich" engineering environment[425].

Highlight 5-8: Future Work Lab[426]

The Fraunhofer Institute for Manufacturing Engineering and Automation has developed a concept center to demonstrate the future of manufacturing technologies, with tangible showcases, workshops and training programs targeted at industry, associations, students and future workers. There are three elements to the Future Work Lab that are relevant for these stakeholders.

- The Demonstration Center hosts multiple examples of how technologies and applications that are already available today can fundamentally shape the industrial workplaces of the future
- The "Fit for Future Work" expertise development and consulting center offers seminars, workshops and trainings for individuals to become familiar with the core concepts of Industry 4.0
- The "Work in Progress" ideas center for work research promotes scientific dialog and research into future production techniques and processes, and accelerates the diffusion of research knowledge into industry practices.

#3.2 Incorporating non-technical disciplines

The new age needs highly skilled, flexible, emotionally and socially intelligent manufacturing professionals. Focussing on technical skills only is not enough. There is a clear need to incorporate non-technical disciplines into the curriculum, including

423 Impuls Foundation (2019) "Impuls compact: Engineers for Industrie 4.0", VDMA (The Mechanical Engineering Industry Association), March 2019
424 *Ibid.*
425 Kamp. A (2016) "Engineering Education in the Rapidly Changing World: Rethinking the Vision for Higher Engineering Education", 2nd revised edition, Delft University of Technology and 4TU.Centre for Engineering Education
426 https://www.ipa.fraunhofer.de/en/cooperation/industry-on-campus/future-work-lab.html

creative thinking and problem-solving, communication, project management, arts, etc., in order to develop cross-cutting competencies and a mind-set beyond technical expertise.

The curricula of the new age particularly need to stimulate **creativity and innovation skills, "out of the box" thinking, divergent thinking, opinion generating, and subjective interpretations**. These principles will have to complement, and partly replace, the teaching styles and skills that are traditionally associated with engineering, such as abstract thinking, a focus on correct and precise answers, and a disposition toward objectivity[427].

Non-technical skills in engineering become at least as important as the technical ones[428]. For companies and organisations with their own training centres or private universities, **recruitment on the basis of specific technical knowledge becomes less important than recruiting a person with great potential[429]**. Companies increasingly acknowledge that it matters less if a graduate has a deep knowledge of, for example, signals and systems or microsystems engineering, if he/she has proven to be a fast learner, a hard worker, an excellent communicator and intensely loyal to his/her employer. Companies also indicate that they can repair a lack in technical knowledge much easier than to advance the essential non-technical skills[430].

At the same time, **changes in the curriculum should not adversely affect the technical depth**, as the technical expertise in engineering remains crucial. Therefore, adding the required breadth and enrichment should not lead to teaching less and less about more and more[431], but rather to finding **an optimal integrated way** of training technical and non-technical skills simultaneously, in a balanced partnership with human factors and business acumen[432].

#3.3 Paying special attention to ethics, social inclusion, diversity and sustainability

The workforce of the new age needs to master **ethical literacy**. Questions of ethics, and specifically with regard to diversity, social inclusion and sustainability, are often emphasised by stakeholders as being essential for engineers to make a positive contribution to society[433]. Existing research shows that students from diverse fields find ethical concepts new, stimulating and crucial for their careers[434]. Ethical concepts provide a framework for thinking about sustainable practices in their personal and professional lives. Future research efforts need to be devoted to exploring different teaching strategies and different institutions, with the use of pre/post studies[435].

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427 https://www.ipa.fraunhofer.de/en/cooperation/industry-on-campus/future-work-lab.html
428 *Ibid*.
429 *Ibid*.
430 *Ibid*.
431 *Ibid*.
432 Kamp. A (2016) "Engineering Education in the Rapidly Changing World: Rethinking the Vision for Higher Engineering Education", 2nd revised edition, Delft University of Technology and 4TU.Centre for Engineering Education
433 GEDC (2017) "GEDC Industry Forum 2017: Designing the Future of Engineering Education", Industry Forum Report
434 Biedenweg K., C. Monroe M.C., Oxarart A. (2013) "The importance of teaching ethics of sustainability", International Journal of Sustainability in Higher Education, 4 January 2013
435 *Ibid*.

A course on ethical principles is a useful and potentially critical component to any curriculum aiming to prepare future professionals to be effective contributors to a sustainable society. Education and training providers need to adopt the course concepts and learning tools to enhance their curricula, and companies will benefit from entry-level professionals with a solid ethical foundation for making more sustainability-oriented decisions[436]. Special attention needs to be paid to incorporating Strategic Development Goals (SDGs) into the curricula, for example, in the form of projects or case studies.

Highlight 5-9: CARONTE: Continuing education and scientific information literacy on Raw Materials for professionals[437]

CARONTE project targets R&D Managers from companies operating in the raw materials sector and focusing their activities on recycling and substitution themes. The project main impact refers to learning/improving digital competencies within SMEs: access relevant information to address innovation; build-up of a collaborative culture within companies; reduce the time-to-market of innovative products by reducing wasting time due to the multiplication of information searching efforts; companies savings in respect of information access.

#3.4 Offering a holistic view of a product and system life cycles

The curricula for the new age need to focus on the holistic view of a product and system life cycles, in which students learn **to alternate between the abstract and the precisely detailed, to deconstruct big problems and accept failure and model real-life situations by simplifying assumptions**[438]. Specifically, it implies making sure that students acquire a conceptual understanding by learning about the theories and principles of physical phenomena and engineering sciences, as well as about modelling real-life problems, to be able to transfer their knowledge into solutions and feasible designs of an appropriate level of complexity[439].

#3.5 Teaching students how to acquire new knowledge[440]

In the past, expert knowledge used to be the key capability. In the new age, however, knowledge is no longer the end goal of an engineering study but an on-going activity of learning-to-think and learning-to-learn. Engineers of the future will no longer have to memorise everything they learnt at school. Most of what students learn today in a Master's specialisation will be obsolete within a couple of years after graduating. Graduates thus become the "grazers and collectors" of information and knowledge. They actively use search engines that highlight the relevant fragments of the text; however, those provide little incentive for reading the documents as a whole. There is a clear need for a shift of educational methods from trying to impose large amounts of expert knowledge on students (which primarily serves the needs of a minority of students who pursue an academic career), towards **teaching how to acquire**

436 Biedenweg K., C. Monroe M.C., Oxarart A. (2013) "The importance of teaching ethics of sustainability", International Journal of Sustainability in Higher Education, 4 January 2013
437 https://www.caronteproject.eu/
438 Kamp. A (2016) "Engineering Education in the Rapidly Changing World: Rethinking the Vision for Higher Engineering Education", 2nd revised edition, Delft University of Technology and 4TU.Centre for Engineering Education
439 *Ibid*.
440 *Ibid*.

knowledge from the 'ocean' of data, and what to make of it when it has been found[441]. In the future, Internet will form the main source of knowledge of the university and workplace. The abovementioned developments signify the need for **new-media literacy** and especially **digital literacy** to become key components of engineering education[442].

#3.6 Teaching students and workers about safety and ergonomics at work

Students and workers also need to be taught **to be mindful of their physical and mental health**. Although this is a primary responsibility of the management of their future workplace, learners need to be educated about the importance of maintaining good health, the possible consequences of risk exposure and also what can be done about it. Then they will be able to bring with them to their workplace a culture of asking for safety, good ergonomics and usability. Physical and cognitive ergonomics[443], work environment, shift work and risks are all aspects they need to be taught to recognise as real threats to their long-term well-being and work ability. A demand for good workplace health and design should be fostered in learners in such a way that they understand what is needed for a certain vocation to be a safe, long-term choice where they can safely keep their motivation and health[444].

Highlight 5-10: Socially Sustainable Manufacturing[445]

Under the purview of the Department of Product and Production Development at Chalmers University of Technology, the SO SMART initiative aims to establish research roadmaps, scenarios and guidelines for the social well-being of employees in the factories of the future – which includes the needs and concerns of the individual, the factory and the society.

The SO SMART project focuses on six main challenges:

- Value Creation
- Stimulating Work Environment
- Life-Work Balance
- Business Perspective
- Key Indicators for Success
- Embeddedness in Society

In doing so, the project will deliver on the following core objectives:

- Ecosystem, scenarios and indicators for socially sustainable manufacturing
- Visions and strategies for sustainable Factories of the Future
- Recommendations and roadmaps for research and innovation in Horizon 2020.

441 Kamp. A (2016) "Engineering Education in the Rapidly Changing World: Rethinking the Vision for Higher Engineering Education", 2nd revised edition, Delft University of Technology and 4TU.Centre for Engineering Education

442 *Ibid*.

443 Berlin, C. and Adams, C. (2017) "Production Ergonomics: Designing Work Systems to Support Optimal Human Performance", London: Ubiquity Press

444 Stakeholder inputs

445 https://www.chalmers.se/en/projects/Pages/so-smart.aspx

5.6. Learning environment

Learning environment includes types of environment that is created during the educational or training program. The learning environment refers to both the qualities of the space (both physical and virtual) in which learning activities are situated, and other intangible aspects that support and enhance the social and emotional dimensions of learning.

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

Figure 5-5 provides an overview of the conceptual principles that were derived from the analysis specifically for Learning environment.

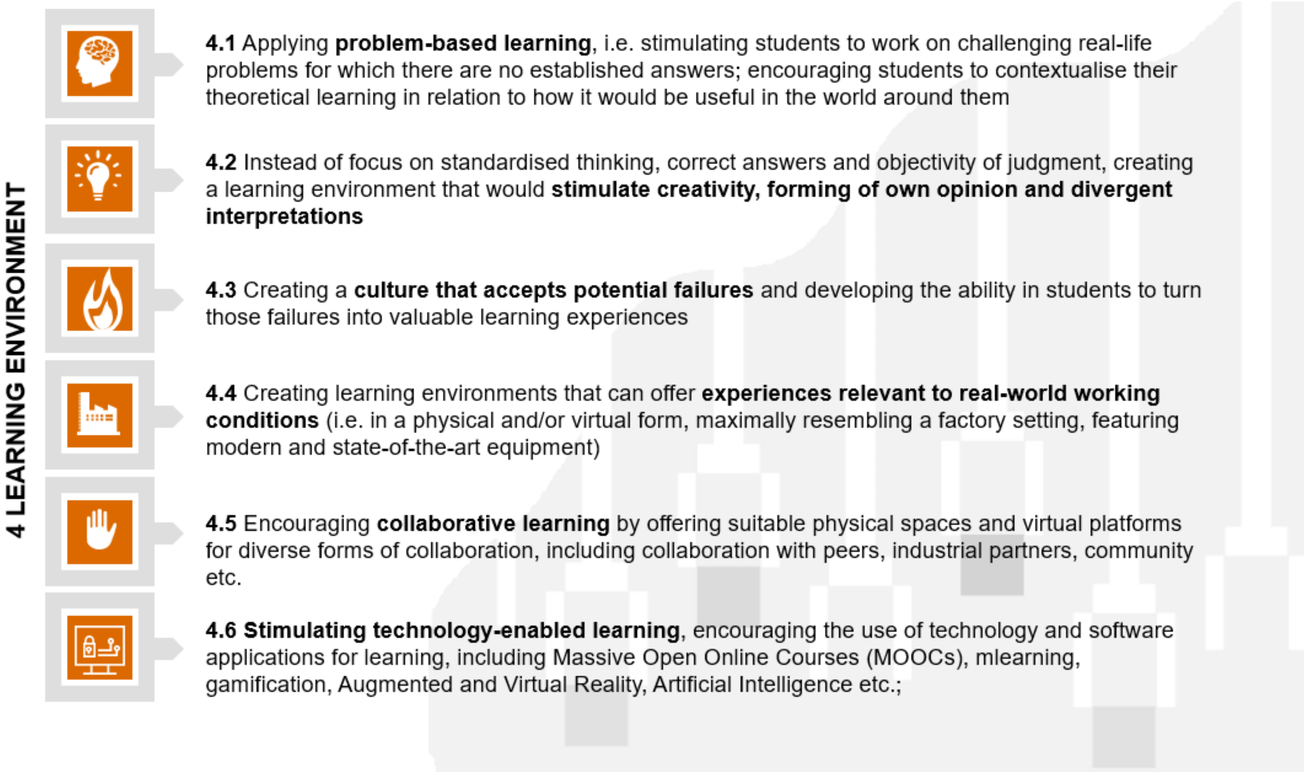


FIGURE 5-5: Six conceptual principles for Learning Environment

#4.1 Applying problem-based learning

Applying problem-based learning (PBL) implies stimulating learners to work on challenging real-life problems for which there are no established answers, and encouraging learners to contextualise their theoretical learning in relation to how it would be useful in the world around them.

Specifically, PBL entails posing a question (often open-ended) to a group of learners who are provided with resources and a facilitator, but with no lectures[446]. In the engineering context, the problem might be related to design (e.g. devise the lowest cost system meeting the specified requirements; or advise a car manufacturer how to reduce the weight of their car door without losing impact resistance and without increasing cost). Well-designed problems require learners to engage in both qualitative and quantitative research[447]. PBL implies that the learners work in groups or teams. The latter means that, before or during their first PBL exercise, they will need some training in the basics of team work. PBL can be used within a module, as the basis for a whole module, or as the context for a complete programme[448]. The notion of PBL is similar to project-based learning, having many similar characteristics, and particularly the lack of lectures and the reliance on the own efforts of learners to discover and understand[449].

The key benefits of the approach include the following[450]:

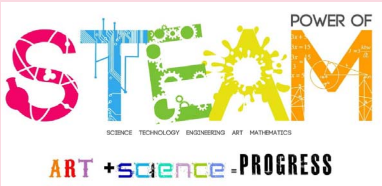
- **Assessment is multi-dimensional and holistic**, measuring both breadth and depth of learners' capability across a number of metrics, and can be evidenced in multiple forms;
- **Learning is authentic, engaging, and addresses meaningful outputs and products**; learners understand the purpose of learning, and educational experiences relate to the real world;
- **Knowledge acquisition and skill development are treated as equally important**, blurring the lines between academic and vocational learning; learning by doing is core, and the creation of new knowledge and expertise is highly valued;
- **Learning is student-driven** and co-constructed with a range of professionals/ facilitators;
- **Accountability shifts downwards**, and the balance between individual and collective accountability ensures a sense of ownership of learning;
- **Time is structured** to enable high productivity and accelerated progress;
- There is **a strong focus on partnerships** and leveraging external expertise and resources, and utilising the wider learning assets across communities.

446 http://teachingengineering.liv.ac.uk/book-section/5-4-problem-based-learning/
447 *Ibid*.
448 *Ibid*.
449 *Ibid*.
450 https://my.pblworks.org/resource/blog/5_emerging_trends_in_project_based_learning

#4.2 Stimulating creativity, forming of own opinion and divergent interpretations

Instead of focus on standardised thinking, correct answers and objectivity of judgment, there is a need for creating a learning environment that would stimulate creativity, forming of own opinion and divergent interpretations[451].

Highlight 5-11: STEM to STEAM: The "Arts" and Its Importance in STEM Education[452]



The main difference between STEM and STEAM is that STEM refers to a modern approach to science and related subjects focusing on solving problems with critical thinking and analytical skills, while STEAM education explores the same subjects, but incorporates creative thinking and applied arts into teaching and real situations. The "A" in STEAM is a term that represents liberal arts, language arts, social studies, physical arts, fine arts, and music. Art here is about discovering and creating ingenious ways of problem-solving, integrating principles and presenting information. By adding the elements of art to STEM-based thinking, students can use both sides of their brain—analytical and creative— to develop the best thinkers of tomorrow. While STEM might be necessary for technological progress, without the arts, it is hardly possible for students to reach their full potential.

There is a need to address also other intangible aspects that are required in work environments, i.e. the **social and emotional dimensions**[453] of learning and work. The latter require spaces that allow for reflection, discussing frustrations, sharing resources and obtaining help with making difficult choices. In addition to supporting the effectiveness of individual learning, such an environment would also train valuable soft skills, such as social awareness, relationship skills and responsible decision-making, that all are crucial for a work environment of the new age[454].

#4.3 Creating a culture that accepts potential failures

The progress within the manufacturing domain heavily relies on continuous experimentation with new technologies, processes and application areas, and requires the courage to try something different. This approach inevitably implies a portion of failure in the experiments. Such failures may, for example, include failures in design, wrong timing etc. **Innovation can only be possible with the acceptance of potential failures and the ability to turn those into a valuable learning experience, and preferably into a winning situation**. The learners should therefore be trained the ability to learn from unexpected results and transform these results into new opportunities[455].

451 Kamp. A (2016) "Engineering Education in the Rapidly Changing World: Rethinking the Vision for Higher Engineering Education", 2nd revised edition, Delft University of Technology and 4TU.Centre for Engineering Education

452 https://www.makeblock.com/official-blog/218830.html

453 https://www.newvisions.org/blog/entry/social-emotional-learning-and-adult-learning-connecting-the-dots

454 https://casel.org/what-is-sel/

455 Based on PwC (2016) "Skills for Key Enabling Technologies in Europe: State-of-Play, Supply and Demand, Strategy,
Recommendations and Sectoral Pilot", Final Report for the European Commission

The educational system needs to offer learners an environment in which they will be able to run experiments to learn as rapidly as possible. Learners should be encouraged to try out various strategies, approaches, models etc. without a fear of failure. It is important to note, that the acceptance of this competence requires fundamental mentality change at all levels, including the level of individuals, companies and policy makers in Europe. As suggested by the stakeholders, currently, Europe is dominated by risk-averse culture, with failures being associated primarily with a negative experience and damage for the reputation of the involved individuals and parties. The situation is, however, complicated by a capital-intensive nature of the manufacturing domain, involving lengthy and highly costly research and innovation development periods, which is particularly sensitive for private investors, start-ups and SMEs[456]. Experiments in virtual environments offer a promising and 'safe' alternative in this respect.

Highlight 5-12: Learning Garage[457]

KU Leuven's Agora Learning Center hosts a monthly initiative by Cronos Leuven and LCIE to enable ambitious students to learn about emerging technologies regardless of their academic background and to develop entrepreneurial business ideas based on the application of these technologies.

Typically 7 interdisciplinary teams are formed every month, and they attend 4 evening sessions focused on a particular technology plus a pitch training during the course of the month, and finally they pitch their concept at the end of the month.

In this way, students are trained to solve open-ended problems creatively and practically, and they implicitly learn that the cost of a bad idea is just one more lesson to do better in future.

#4.4 Offering experiences relevant to real-world working conditions

There is a need for learning environments that can offer **experiences relevant to real-world working conditions** in a physical and/or virtual form, maximally resembling a factory setting, featuring modern and state-of-the-art equipment. Such an environment does not only need to support hands-on training and learning-by-doing[458], but also serve as a test-bed for new technologies or processes, or simply expose workers to new technologies and processes. These environments can feature a variety of spatial configurations suitable for various kinds of content and delivery methods such as classroom learning, group assignments, self-paced learning, hands-on demonstrations, practice hours with new hardware/software, virtual reality sessions etc.

456 Based on PwC (2016) "Skills for Key Enabling Technologies in Europe: State-of-Play, Supply and Demand, Strategy,
Recommendations and Sectoral Pilot", Final Report for the European Commission
457 https://lcie.be/en/learning-garage/programme/
458 http://www.engineersjournal.ie/2016/02/23/learning-factories-a-new-approach-to-training-in-advanced-manufacturing/

Highlight 5-13: Stena Industry Innovation Lab at Chalmers University of Technology[459]

Stena Industry Innovation Lab represents a promising learning environment for both students and industrial partners. It is a **technological test-bed environment** for production system technology, that showcases and makes available a wide variety of technology and tools for production tasks, such as assembly, quality control, logistics etc. It is an environment that encourages trying out, experimenting and creatively building workstations and flows. The lab offers fast communication systems with 5G, collaborative robots, as well as virtual and augmented reality techniques for assembly.

Specifically, there are four different demonstrators in the lab, all of which highlight digitalisation and industry 4.0: (1) Mini Factory 4.0; (2) Cloud Computing; (3) Collaborative robots – Cobots; and (4) Simulation and training with virtual reality (VR) and augmented reality (AR) technologies. The first two demonstrators are about communication and presentation of data. The other two are about aids for operators in the form of training, simulation and robots. The new equipment will provide users with knowledge of digitised production and understanding of how, when and where to use the new digital tools. This includes about how products, machines and people can communicate with each other and with other systems. The equipment will be used in teaching and research, as well as in industrial cooperation. The lab is available for students in mechanical and mechatronics programs at Chalmers Lindholmen. At the same time, the lab also has active cooperation with researchers in information and communication technologies and researchers who work with integration between man and machine, as well as with industrial companies.

#4.5 Encouraging collaborative learning

This conceptual principle implies encouraging **collaborative learning** by offering suitable physical spaces and virtual platforms for diverse forms of collaboration, including collaboration with peers, industrial partners, community etc.

Students and workers should view their workplace as a **socio-technical system** and not just a technical one. This means that they need to learn that the success of a high-tech environment does not rely entirely on the degree of advancement of the technology, but also on the know-how and maturity of the people that interact with it. To this end, it is highly important for them to develop collegiality, a spirit of helping each other to solve problems, and a culture of welcoming suggestions and the voicing of when something does not seem right. Work in project teams therefore needs to be encouraged as much as possible. In real-life workplaces, competitiveness should be between companies and not between teammates[460].

Manufacturing-related learning environments need to serve as a meeting hub, presentation space or library, which may be compelling to visit even when there are no active courses. They may feature regular talks and knowledge-sharing sessions from industry experts, showcases and demonstrations by sector-specific vendors and even membership access to industrial journals and other publications. By serving as a melting pot for professionals in industry, these spaces might allow for knowledge and experiences to transfer in informal peer-to-peer settings. Collaborative learning can be stimulated in both physical and virtual settings.

459 https://www.chalmers.se/en/areas-of-advance/production/laboratories/csilab/Pages/default.aspx
460 Stakeholder inputs

Highlight 5-14: Projectcampus: social learning environment[461]

Projectcampus is a social learning app for schools and universities. Students can share and discuss progress in project pages with their teachers, peers and clients. Each course is an online learning community. Projects can be created by staff or students themselves. Each project forms a unique learning journey. Students can follow other projects to learn from each other. They can choose for each post who is able to view it. Projectcampus makes it easy for students to help each other. On the course and project level, students can be supported and inspired by their peers.

#4.6 Stimulating technology-enabled learning

Technology-enabled learning can be defined as learning that is enabled or mediated using digital technology, associated with learning scenarios and interactive activities, for the explicit purpose of training, learning or development[462]. Similar terms refer to technology-enhanced learning, technology-intensive learning, and technology-integrated learning. It implies a wide range of digital learning solutions related to bespoke and off-the-shelf e-learning, Massive Open Online Courses (MOOCs), Open Educational Resources (OER), video content, mobile learning (or m-learning), and more recently Virtual/Augmented reality (VR/AR), gamification, Artificial Intelligence (AI) solutions etc.

The emphasis needs to be put *not* on the education and training with a digital component, but rather on the fact that the world itself becomes increasingly digital and hence education and training should remain relevant in that context. In other words, technology-enabled learning is not a simple matter of digitalising existing material and making it available online, but more fundamentally responding to the new opportunities and challenges made possible by digitalisation. Education and training that are relevant to the increasingly digital world will touch on digital/online topics in their learning content, and will also differ from traditional learning in terms of delivery media[463].

461 http://projectcamp.us
462 Based on the definition from EU15 Ltd (2016) "SMEs & e-learning (SMEELEARN) – e-learning Best Practice Guide", Erasmus+ project nr. 2014-1-UK01-KA202-001610
463 PwC (2019) "Promoting Online Training Opportunities for the Workforce in Europe", Final Report, prepared for DG GROW/EASME of the European Commission, October 2019

Highlight 5-15: SELFIE: Self-reflection on Effective Learning by Fostering the use of Innovative Educational Technologies[464]

SELFIE is a tool designed to help schools embed digital technologies into teaching, learning and student assessment. It can highlight what is working well, where improvement is needed and what the priorities should be. The tool is currently available in the 24 official languages of the European Union with more languages to be added over time. SELFIE anonymously gathers the views of students, teachers and school leaders on how technology is used in their school. This is done using short statements and questions and a simple 1-5 agreement scale. The statements cover areas such as leadership, infrastructure, teacher training and students' digital competence.

Specific types of technology enabled-learning will be addressed in more detail below.

5.7. Remaining elements of the framework

The remaining elements of the framework include Delivery mechanisms, Assessment, Recognition and Quality. As highlighted above, these elements of the framework will be addressed only briefly, in order to sustain a holistic view of curriculum development and implementation.

5.7.1. Delivery mechanisms

Delivery mechanisms refer to the means by which learners experience and access education/training. They may include in-person delivery where teachers/trainers and learners interact face-to-face, via electronic delivery, and blended delivery (which includes a combination of methods).

Specific types of technology enabled-learning include[465]:

- **E- and m-Learning**: with the improving economics of cloud computing, the promise of e-learning anytime anywhere is becoming a reality[466]. Moreover, cloud tools such as shared folders and collaborative document editing allow groups of learners to participate and tackle assignments collectively rather than just individually. The ubiquity of smartphones have also unlocked the possibility of m-Learning[467]. However, m-Learning cannot replicate e-Learning content directly due to the nature and usage of mobile devices[468]. For example, m-learning is well-suited for bite-sized learning with practical relevance rather than longer content with more theoretical aspects[469].

- **MOOCs and SPOCs**: MOOCs are rapidly gaining popularity, especially with the growing recognition of platforms like EdX[470], Coursera[471] and FutureLearn[472].

464 https://ec.europa.eu/education/schools-go-digital/about-selfie_en
465 PwC analysis incorporating multiple expert sources
466 https://www.opencolleges.edu.au/informed/features/the-ten-emerging-technologies-in-education-and-how-they-are-being-used-across-the-globe/
467 https://www.opencolleges.edu.au/informed/features/the-ten-emerging-technologies-in-education-and-how-they-are-being-used-across-the-globe/
468 https://elearningindustry.com/top-5-design-considerations-for-creating-mobile-learning
469 https://www.infoprolearning.com/blog/9-guidelines-to-design-fantastic-mobile-learning-mlearning/
470 https://www.edx.org

MOOCs allow hundreds of learners, typically adults, across the world to follow courses in a self-paced manner. Typically, courses on the above-mentioned platforms tend to be more theoretically grounded since they are offered by universities. On the other hand, many MOOC platforms also feature active forums where learners freely discuss and collaborate with one another. However many courses are still not officially accredited or recognised by employers – reflected in low completion rates. Moreover, the assessment process for MOOCs still struggles to find the balance between evaluating level of comprehension and the need to simplify answer assessment due to sheer number of participants. In response to some of these issues, SPOCs have emerged targeting smaller cohorts in more relevant learning material. Both MOOCs and SPOCs have high potential but must continue to evolve to better suit the needs of adult learners[473].

- **Games and gamification**: game-based learning has shown potential to be a useful training and motivation tool, and has gone far beyond merely integrating digital and online games into curricula[474]. Game-based experiences can be effective in scaffolding concepts in an intuitive way and providing interactive simulations of real-world experiences. These game experiences may also be in the context of blended learning, wherein the game sets up scenarios to which a team in the real-world must discuss and respond. Beyond the initial learning experience, gamification can also follow learners in their day-to-day activities, awarding points for applying their newly learned skills. This is especially useful in contexts that require changes in habits or behaviours.

- **Wearables, IoT and advanced learning analytics**: wearable electronics, embedded sensors in the learning environment and software-based tracking of learning effectiveness are promising avenues to enhance and personalise learning outcomes[475]. While there are specific data privacy issues to be considered, learning analytics also hold the promise of adapting content and pedagogy to individual learning pace and style. Within the context of AMT, workers exposed to wearables, IoT and advanced analytics in the learning context can gain an intuitive understanding for the value of data-driven processes in their own work.

    - Advanced learning analytics may also bring to bear Artificial Intelligence, which could help to power adaptive learning systems[476]. For example, a traditional MOOC currently offers standardised content to hundreds of users. With adaptive learning algorithms, MOOC content might be paced differently depending on the needs of the learner, and may include more or less multimedia elements depending on the individual's preferred learning style. As such, learning analytics points away from a one-size-fits-all model of training.

471 https://www.coursera.org
472 https://www.futurelearn.com
473 https://trainingmag.com/trgmag-article/do's-don'ts-moocs-spocs/
474 https://www.opencolleges.edu.au/informed/features/the-ten-emerging-technologies-in-education-and-how-they-are-being-used-across-the-globe/
475 https://www.opencolleges.edu.au/informed/features/the-ten-emerging-technologies-in-education-and-how-they-are-being-used-across-the-globe/
476 https://www.opencolleges.edu.au/informed/features/6-emerging-educational-technologies-used-across-globe/

- **Immersive technologies like Virtual and Augmented Reality (VR/AR)** (including haptic technology, acoustic and visual elements) are increasingly being explored in the context of education. However, it is critical to note that developing educational content in VR/AR is not simply replication e-Learning content in 360 degrees. Typically, it can be said that VR technology is best used to create experiences that are rare, expensive, dangerous or empathetic. Due to their immersive "feeling like you are there" quality, such experiences can effectively introduce learners to certain scenarios that may not always be possible to recreate in the real world. The VR world can also be used to emphasise certain aspects that learners might otherwise miss in the real-world. In fact, research shows that people helps participants learn faster through better recall[477]. AR, on the other hand, is able to introduce a feeling of "sixth sense" by adding information around real-world objects that may not be obvious or intuitive. Moreover, AR is better able to depict digital objects at human scale, further helping learners to have an intuitive experience.

Beyond just meeting learning objectives, familiarity with VR/AR will be important in the AMT-equipped factories of the future. For example, complex CAD objects can be better viewed and designed in a 3D virtual environment than on 2D screens. AR headsets will provide workers the additional situational awareness required for higher-order tasks and data-driven decision making.

Finally, platforms like HMH Marketplace[478] and other **digital communities that offer new opportunities for both educators and EdTech companies** alike, will become the new norm[479]. HMH Marketplace is an online destination for educators to discover, share and sell resources that enhance teaching and learning experience. Launched in 2016, it features diverse applications created by EdTech developers and start-ups, ranging from digital learning tools to games and classroom resources, as well as original content made by teachers for teachers, such as lesson plans and instructional materials[480]. For educators, the HMH Marketplace streamlines the search for supplementary education applications, integrating with and supporting core curriculum, as well as providing an opportunity to promote their own original instructional tools and content. For EdTech start-ups, developers and teacher-sellers, the HMH Marketplace offers innovative and interoperable solutions in one seamless offering for teachers. The goal of such a platform is to provide a simple way for educators to find applications and resources that add value to the learning experience, without the need for an exhaustive search, additional log-ins or technical integration with existing platforms[481].

5.7.2. Assessment

Assessment refers to the various methods of evaluation and their relevance to different kinds of educational offerings based on the advantages and disadvantages of each. Common methods of assessment include the following[482]:

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477 https://www.revinax.net/virtual-learning-and-memory/
478 https://www.hmhco.com/
479 Ryan K.J (2016) "4 Things Futurist Alvin Toffler Predicted About Work Back in 1970", Inc.com, 30 June 2016, quoted in Lee Welsh B. (2018) "Education 4.0 — How We Will Learn in the Fourth Industrial Revolution", Medium 18 April 2018
480 https://www.hmhco.com/about-us/press-releases/marketplace
481 *Ibid*.
482 PwC analysis incorporating multiple expert sources

- **Self-assessment:** it involves learners evaluating their own work and progress towards the learning objectives[483]. Through self-assessment, learners are encouraged to reflect on identifying their own knowledge gaps, set realistic goals and decide their pace going forward. Self-assessment also helps teachers to track self-reported progress and level of satisfaction from the class. For self-assessment to be effective, it is necessary to provide learners with clear definitions of what qualifies as good performance. However, experience shows that self-assessment typically tends to be inflated compared to peer assessment and institutional assessment[484]. Thus self-assessment is often limited to learnings that are non-essential, or necessarily complementary to other modes of assessment when pursuing formal certification.

- **Peer assessment:** in a collaborative learning context, peer assessment allows for learners to evaluate each other, and such an assessment may focus on soft skills like teamwork but also technical mastery such as quality of assignment contribution[485]. Peer assessment has the potential to stimulate participants to give feedback and learn from one another, as well as supporting institutional assessment of factors that are not obvious from the assignment alone. For learners to be equipped to provide effective and valid feedback to their peers, assessment criteria need to be clearly defined with comparative examples[486].

    - Peer assessment also has a few limitations in that it is primarily applicable only for collaborative activities (e.g. group projects) and thus in not relevant for individual self-paced learnings. Peer assessment may also be heavily influenced by the level of rapport shared by group members – which may be particularly problematic when trying to objectively assess the technical merits of a peer's contribution. Moreover, peer assessment is also expected to be qualitatively different when collaboration is primarily done online as there are fewer opportunities to form human connections other than transaction of ideas and materials.

- **Institutional assessment:** it may refer to manual evaluation of learners' responses in quizzes, interviews, assignments, presentations, practical examinations and other means of formal evaluation, or digitised or automated modes of assessment such as optical answer sheets, online quizzes with pre-defined answers or even AI-enabled personalised testing methods[487,488,489]. Institutional assessment is typically associated with the quality and rigor of formal education, and ensuring accreditation is more likely to be recognised and valued. There are also many forms of formal evaluation methods of

483 https://teachingcommons.stanford.edu/resources/teaching/evaluating-students/assessing-student-learning/student-self-assessment
484 https://www.tp.edu.sg/staticfiles/TP/files/centres/pbl/pbl_kelvin_and_ho_keat.pdf
485 https://teachingcommons.stanford.edu/resources/teaching/evaluating-students/assessing-student-learning/peer-assessment
486 http://citt.ufl.edu/online-teaching-resources/assessments/peer-review-in-online-learning/
487 https://teachingcommons.stanford.edu/resources/teaching/evaluating-students/creating-assignments/papers-projects-and-presentations
488 https://teachingcommons.stanford.edu/resources/teaching/evaluating-students/assessing-student-learning/automated-grading-exercises
489 https://teachingcommons.stanford.edu/resources/teaching/evaluating-students/assessing-student-learning/artificial-intelligence-assessment

different intensity and length that can be applied for different kinds of learning content and to evaluate different kinds of learning outcomes.

- However, the versatility and depth of manual assessment is countered by low speed and volume of processing compared to automated methods. This will remain the primary trade-off.
- Automated means of assessment such as answering multiple-choice questions on optical answer sheets or answering questions in an online form may provide the necessary speed to process hundreds of submissions, in some cases giving participants immediate feedback. However, these methods typically cannot measure intangible elements of learning such as soft skills, and also would struggle with open-ended questions. For online courses, some of the consulted stakeholders reported having good experiences with the projectcamp.us, offering an electronic system for tracking progress of individual learners [490].
- Some organisations are experimenting with video-chat functionalities combined with AI algorithms to automate the assessment process while also evaluating more holistic elements such as expressions, tone of voice, level of confidence etc.[491]. These modes of assessment are best done using a combination of human judgement and complementary data from AI analysis.

5.7.3. Recognition

Recognition traditionally refers to the process of issuing, accepting and acknowledging accredited certification or titles that have formal value for mastery of skills or knowledge[492]. However, there are also emerging configurations, whereby non-institutional actors may also confer symbols of recognition based on level of participation, contribution and/or impact. As such, this dimension focuses on the following[493]:

- **Formal (institutional) recognition:** it takes the form of diploma and degree certification. However, to become a true pillar of a lifelong learning strategy, recognition must expand to areas that are as yet underserved, such as accreditation schemes for prior training, non-technical or vocational experience, and compatible international certifications. Internationally, there has been broad acceptance for the notion of qualification frameworks (QFs) as an instrument to classify qualifications at every level by minimum expected learning outcomes[494].
  - In the context of AMT, most content and accreditation is currently technically oriented in the domain of engineering. Moreover, the title of "Engineer" is currently not protected in the sense that there is no necessity for re-certification to ensure learner is up-to-date with the state-of-the-art. There are also not many avenues to validate informal

490 See Highlight 5-6 and http://projectcamp.us
491 https://www.cut-e.com/solutions/video-assessment/
492 http://uil.unesco.org/lifelong-learning/recognition-validation-accreditation
493 PwC analysis incorporating multiple expert sources
494 http://uil.unesco.org/lifelong-learning/qualification-frameworks/global-inventory-regional-and-national-qualifications-0

learning, tacit knowledge or experience. These shortcomings must be addressed to properly serve a comprehensive lifelong learning policy.

  - Most continuing learning systems may cater to traditional notions of cumulative specialisation and need to recognise the emerging need for multidisciplinary skills acquisition and application. This has implications for learning content, e.g. how to cater to a broad audience who don't all have the same background – and pedagogy – how to teach core skills to an audience who will apply it in different contexts in their various sectors.

- **Informal (social) recognition**: it refers to the acknowledgement of knowledge, skills and/or competencies by peers or stakeholders who work with/around the individual[495]. The biggest difference between formal and informal recognition is that there may not be an institutional actor to acknowledge and award a certification for the latter. However, in practice, informal recognition is already influential and can be enhanced further. For example, many employers value relevant work experience more than certification alone, and this is a powerful signal as to the value of informal recognition. In recent years, major companies have announced that they will be dropping a formal requirement for degree certification when assessing candidates for positions, as long they demonstrate the relevant skills and proficiency[496].

  - Informal recognition can be organically identified and further enhanced in the area of communities of practice[497]. Online and offline, professionals with similar interests, backgrounds or job scopes, find ways to connect and organise. Within this context, individuals who share their knowledge and contribute their expertise may be recognised, and this social recognition could be further formalised. Notably, IBM implemented a version of open badges to allow developer communities to essentially crowdsource recognition based on their interactions, demonstrations and contributions[498].

5.7.4. Quality

Developing clear and effective measures of educational quality is an important venue for research[499]. Quality refers to the expectations of both students, workers and employers[500]:

- **Employer expectations for quality in professional training:** to a large extent, the quality of employees' professional training relates directly to the

495 http://www.lifelong-learning.lu/Detail/Lexique/Accueil/reconnaissance-des-acquis-d_apprentissage/en
496 https://www.techrepublic.com/article/google-apple-among-15-top-companies-where-you-can-get-hired-without-a-college-degree/
497 https://thesystemsthinker.com/communities-of-practice-learning-as-a-social-system/
498 https://www.ibm.com/developerworks/community/groups/service/html/communityview?communityUuid=ee240a4b-d911-46d3-b815-fc8a70d67b27
499 Serdyukov P. (2017) "Innovation in education: what works, what doesn't, and what to do about it?", Journal of Research in Innovative Teaching & Learning, 10(1), 4-33.
500 PwC analysis incorporating multiple expert sources

economic success of the enterprise. However, employers typically expect both existing and prospective employees to add value to the company above and beyond a baseline productivity[501]. In other words, employers are looking for more than just qualifications, and focusing also on values, behaviours and skillsets[502]. Values such as integrity, accountability, continuous improvement and work ethic are desired. They also prefer behaviours such as adaptability, business acumen and authenticity. Finally, skillsets such as critical thinking, digital literacy, data analysis and business language(s) proficiency are also highly valued, in addition to technical expertise.

  - These expectations thus provide a broad terrain of directions for education and training providers to incorporate into their educational offers to train value-added employees.

- Learner **expectations for quality in professional training**: in general, learners will also demand outcomes from professional training that improve their employability or value-add for their employer – thus many of the prior points are implied. In addition, learners are well aware that their individual career trajectory is not necessarily tied to one single employer, and as such will also appreciate some additional qualities[503,504]. These many include:

  - the broader context in which particular trainings are relevant,
  - exposure to peers and their occupations,
  - (in)formal support with further learning/career development,
  - (in the case of online learning) flexibility of time, place and pace,
  - support with personalising one's learning plan,
  - reasonable cost and time investment,
  - reasonable work load with clear tasks and regular feedback,
  - ability to connect, discuss and collaborate with other learners and teachers,
  - supplementary support like strategies for job interviews or guidance on crafting better resumes.

In the context of technical education, access to databases, reference material and professionally relevant information is also highly valued. Extra personalised help is highly desired for particularly difficult course material.

Furthermore, an important aspect of Quality refers to the *usability* of the educational/training offer. The ease of access, use, comprehension and retention of the information offered is crucial for the learner's success, regardless of whether it is m-, e-, VR/AR or real-life learning. Bad interface design, feedback mechanisms or similar may severely impact the learner's motivation to learn, if (especially self-assessing) systems are difficult to navigate, access functions in or complete. This aspect is particularly relevant when much of the learning is to be proffered via digital systems.

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501 https://learningforward.org/docs/default-source/pdf/why_pd_matters_web.pdf
502 Business Council of Australia – Being Work Ready: A Guide to What Employers Want
503 https://files.eric.ed.gov/fulltext/ED503369.pdf
504 https://www.ncver.edu.au/__data/assets/file/0008/10133/learner-expectations-and-experiences-806.pdf

6. FUTURE PROMOTION AND IMPLEMENTATION ACTIVITIES

The current chapter aims to provide an overview of the actions that are need to ensure a widespread promotion of the curriculum guidelines, as well as to stimulate their implementation at all levels.

As emphasised before, the guidelines aim to offer a source of inspiration, conceptual guidance and good practice examples for both designing fundamentally new educational offers and for advancing existing curricula, depending on the level of required change. The ultimate objective of the guidelines is to equip stakeholders with the relevant analytical base and to trigger actions leading to aligning curricula with the needs of the new industrial age.

- Specific topics covered by the current chapter include: Developing a roadmap for promotion and implementation of the Curriculum Guidelines 4.0;
- Creating a dedicated thematic network/roundtable;
- Addressing the topic of quality labels;
- Monitoring the evolving skill needs; *and*
- Supporting the professional development of educators and trainers.

6.1. Developing a roadmap for promotion and implementation of the Curriculum Guidelines 4.0

In order to achieve impact from the developed Curriculum Guidelines, there is a need to ensure their massive dissemination and the facilitation of their adoption by all key stakeholder groups. Figure 6-1 presents a proposed roadmap for the promotion and implementation of the Curriculum Guidelines 4.0.

The key elements of the roadmap include the following:

- After the presentation of key highlights at the conference of 26 November 2019 and the official release of the Guidelines in January 2020 on the EU Publications website, the **first-stage dissemination** will take place in late January 2020// - early February 2020 among the key stakeholder groups[505] and among the coordinators of the key networks/communities (such as, for example, EUA[506], CECIMO[507], SEMI-Europe[508], Skillman.eu[509], EFFRA[510], EfVET[511] etc.).

- The coordinators of the abovementioned networks/communities will be provided with the necessary communication materials and will be invited to disseminate this information among the specific members of their networks by means of newsletters, websites, direct email campaigns and social media. This approach represents the **second-stage dissemination** and allows for

505 Experts involved in the current initiative by means of expert workshops, online surveys, in-depth interviews and individual expert consultations
506 The European University Association, https://eua.eu/
507 European Association of the Machine Tool Industries, http://www.cecimo.eu/site/
508 http://www.semi.org/eu/
509 https://skillman.eu/
510 European Factories of the Future Research Association
511 European Forum of Technical and Vocational Education and Training, https://www.efvet.org/

ensuring a broad coverage of the targeted audience via familiar communication channels. The second-stage dissemination will take place in February 2020.

- Following the two-stage dissemination campaign, the stakeholders will be encouraged to initiate discussions and exchange opinions via a **dedicated LinkedIn Group**. Furthermore, in order to ensure continuity, we suggest creating a **roundtable/thematic network**, with an objective to facilitate further exchanges of experiences, monitor the implementation and keep updating the Guidelines.

- Specifically, the original version of the Guidelines could be made open for stakeholders in a form of an 'open source' approach, allowing for continuous comments, updates and additions.

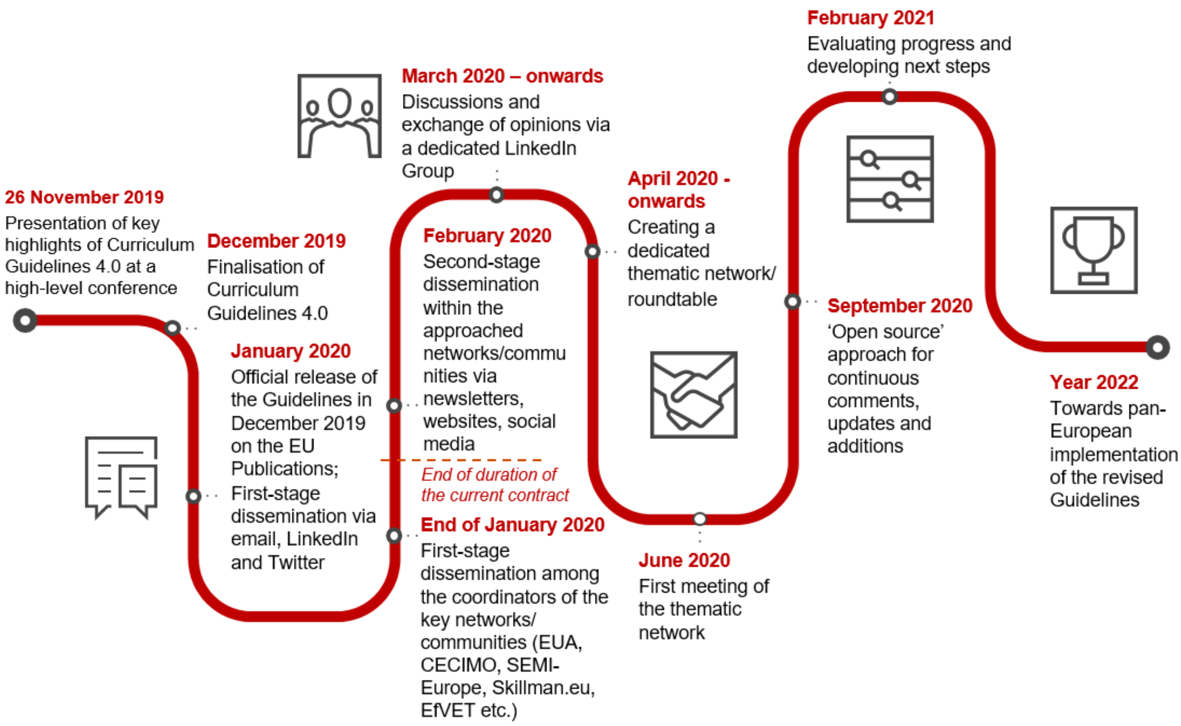


FIGURE 6-1: Proposed roadmap for promotion and implementation of the Curriculum Guidelines 4.0

As emphasised above, the implementation of the guidelines needs to happen at all levels, including micro-, meso- and macro- (see Figure 1-1), with each of the levels having a specific role to play. The identified principles can be implemented individually or jointly, in various combinations, depending on the required level of change.

At the *micro-level* corresponding to the level of the classroom and relating to teachers and learners, the key activities for teachers refer to raising awareness about curriculum guidelines principles among learners; proactively looking for good practice examples and exchanging experiences with professionals who already practice these principles; and proactively initiating discussions with institutional leaders to consider the opportunities to integrate specific principles into the curriculum. Learners, in turn, need to proactively integrate curriculum guidelines principles into their own learning trajectories.

At the *meso-level* corresponding to organisations and their leaders, there is a need for raising awareness about curriculum guidelines principles within the organisation; embedding it into the strategy at the institutional level; and developing operational approach for the implementation of these principles in practice, taking into account specific learners' needs and context.

Finally, at the *macro-level* that corresponds to interorganisational, national and European dimensions, the key directions for action include developing multi-stakeholder initiatives aiming to ensure massive implementation of curriculum guidelines principles in practice, for example, initiatives aiming to create massive awareness about a specific curriculum guidelines principle; to produce specific tools and materials that would enable its effective implementation; to offer virtual and physical collaboration spaces for exchanging experiences, lessons learned and good practices etc.

While actions at micro- and meso-levels often can be implemented individually (at the level of specific teachers and learners and organisations), they would significantly benefit from exchanging experiences, good practices and lessons learned with each other. This exchange could be effectively enhanced by introducing collaboration platforms (both physical and virtual), i.e. dedicated spaces where peer-to-peer collaboration and exchange could take place. For learners and teachers at the micro-level, such platforms could be developed by organisational leaders at the meso-level. At the same time, for similar exchanges between organisations (companies and/or education and training providers), such platforms would need to be developed at the macro-level. Whenever possible, existing platforms should be mobilised for the abovementioned purposes (e.g. Learning/teaching factories, Learning Labs, Living Labs, Innovation Hubs, Makerspaces etc.). Such platforms facilitate expertise and cost sharing, and provide access to a large number of learners to the state-of-the-art equipment, software and technology. The actions to be taken at the macro-level can often only be implemented collectively, i.e. by joining forces, and often of multiple stakeholder groups simultaneously.

6.2. Creating a dedicated thematic network/roundtable

In order to ensure continuity, progress and co-creation efforts, there is a need for developing a dedicated thematic network/roundtable. The latter would enable a continuous dialogue and networking to help manufacturing-related education and training providers to faster adapt their curricula to the needs of the new age.

To this end, this sub-section aims at elaborating recommendations for setting up a dedicated pan-European thematic network. The two **key objectives** of the network would include:

- Promoting the wide adoption of the Curriculum Guidelines across the EU;
- Connecting education and training providers active in manufacturing-related domain and facilitating the exchange of experiences, lessons learned and good practice examples, developed solutions, as well as practical tools that would equip teachers and trainers.

The thematic network needs to be designed in a way that it engages **all the key stakeholder groups** (namely, education and training providers, companies (and particularly SMEs), policy makers (at all levels: EU, MS and regional, to ensure policy impact), learners and supporting structures, e.g. industry associations, cluster organisations, coordinators of relevant multi-stakeholder partnerships/initiatives etc.).

For this network to be a success, it will be crucial to make sure it becomes a **vibrant community of genuinely interested and actively engaged stakeholders** who continuously interact with each other and **gain obvious practical benefits** from their participation in the network. These principles will form the base for our approach to designing recommendations for setting-up such a network.

We propose to approach the design and development of the thematic network in two phases:

- **Phase one: setting-up a virtual (informal) pan-European thematic community**:
    - It implies developing and sustaining a dedicated LinkedIn discussion group, to offer the stakeholder community an online communication platform.
    - The members of the community will be invited to engage in dialogue/discussion with each other, to share their experiences, opinions and suggestions.
    - This informal community will form a preparatory step for the development of a formal thematic network.
- **Phase two: setting-up a formal pan-European thematic network**.
    - The formal thematic network will engage a broader group of stakeholders across all the MS.
    - It needs to have clearly set common goals and resources.
    - It needs to have an established monitoring and evaluation mechanism.
    - It needs to have a sustainable governance structure in place.
    - It needs to have a sustainable learning system in place.

Figure 6-2 presents the key steps for developing a formal thematic network.

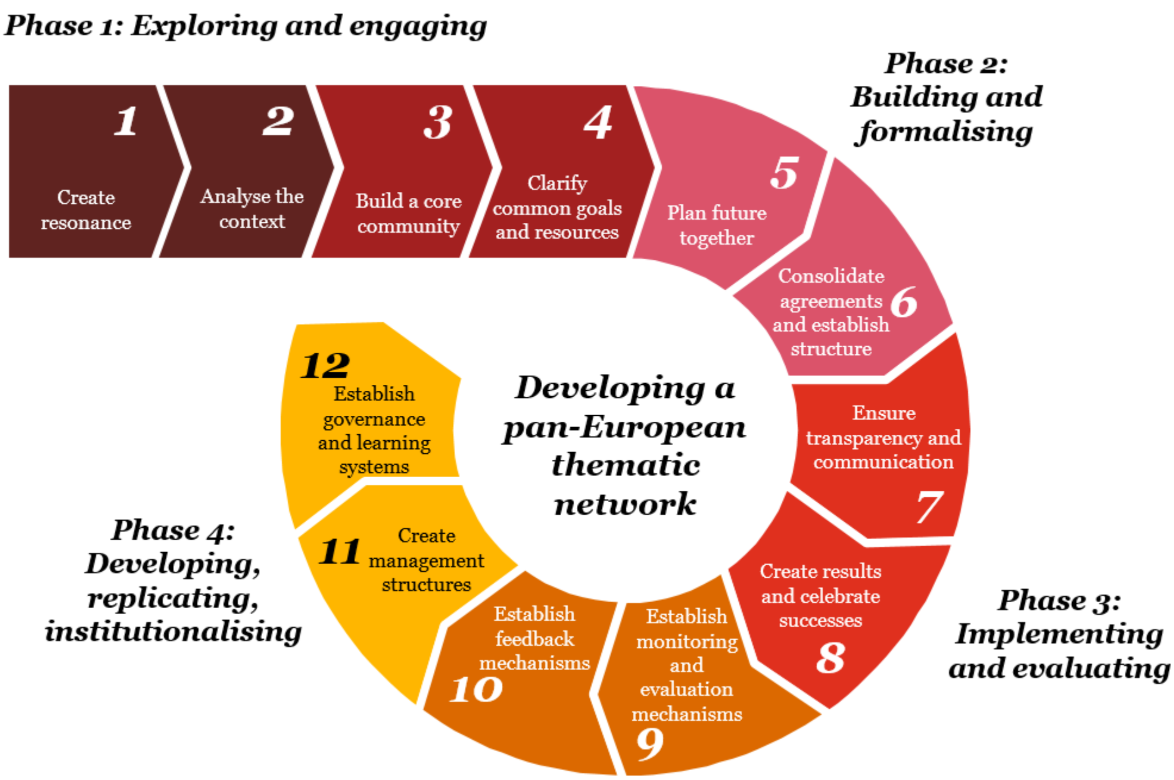


FIGURE 6-2: Key steps for developing a pan-European thematic network (Source: PwC; key concept and some elements adopted from the model used by the Collective Leadership Institute, The World Bank)

Special attention needs to be paid to the following issues:

- Identifying key target groups and ways to ensure their active participation;
- Fine-tuning the objectives of the network and identifying the optimal ways of achieving those objectives; specifically:
    - proposing explicit activities for promoting the wide adoption of the curriculum guidelines across the EU;
    - designing specific measures to offer access to education and training to help enterprises, and specifically SMEs, understand the potential of emerging technologies.
- Developing the approach for:
    - governance and management structures;
    - obtaining relevant resources;
    - practical setting-up and maintenance of the network;
    - communication mechanisms (communication channels (web, social media etc.), form, message types, frequency, division of roles etc.);
    - monitoring, evaluation and feedback mechanisms (including suggestions for KPIs);
    - measures for ensuring the continuity of the network; *and*
    - visual identity elements, awareness raising and communication campaign.

It would be recommended to launch a service contract for the initiation and facilitation of such a thematic network at the EU level. Special attention needs to be paid to developing **synergies with the existing networks and communities**, in order to avoid overlaps of activities. For example, recently, the **Skillman.eu**[512] network has founded a horizontal strategic alliance with other networks of which it has become the leader for a policy-making initiative at the European level, planned for 2020-2021. At present, the Skillman.eu Alliance includes one of the world's largest international network of universities and design schools - Cumulus, based in Finland; the network of university professors - Eapril; the worldwide network of vocational training institutions and experts of TVET, based in the USA - IVETA; and the network of the EU regions - EARLALL based in Brussels.

There is a clear need to build synergies with the activities within the **Blueprint for Sectoral Cooperation on Skills**[513]. The Blueprint in its essence provides a framework for strategic cooperation between key stakeholders such as enterprises, trade unions, research and training institutions and public authorities in a given economic sector. It implies industry-led partnerships that develop sectoral skills strategies and concrete actions, such as new or updated vocational education and training. The overall goal is to help foster new opportunities for investment, innovation, growth and jobs[514].

6.3. Addressing the topic of quality labels

A quality label represents an important tool to assure confidence in the quality of an educational/training programme. Quality labels can enforce the mobility of learners and workers throughout Europe, provided a mutual recognition system is in place. At the same time, **rather than developing multiple new/separate quality labels, there is a need to advance and expand the existing ones, based on the evolving skills needs**[515]. That would allow for minimising the administrative burden, inefficiency and additional costs for the education and training providers.

In the context of the manufacturing domain, the relevant existing European-level quality label refers to EUR-ACE[516] run by the European Network for Accreditation of Engineering Education (ENAEE). It is the European quality label for engineering degree programmes at Bachelor and Master levels. Future efforts need to be devoted to exploring the possibilities **to embed the principles of the Curriculum Guidelines 4.0 into the EUR-ACE label.**

Highlight 6-1: EUR-ACE® System[517]

EUR-ACE® is a framework and accreditation system that provides a set of standards that identifies high-quality engineering degree programmes in Europe and abroad. The EUR-ACE® label is a certificate awarded by an authorised agency to a HEI (Higher Education Institution) in respect of each

512 https://skillman.eu/
513 http://ec.europa.eu/growth/industry/policy/skills_en
514 https://ec.europa.eu/social/main.jsp?catId=738&langId=en&pubId=8164&type=2&furtherPubs=yes
515 One of the key conclusions of the international workshop on the "Role and impact of quality labels in engineering education", involving the European Commission (DG EAC) and key stakeholders and held on 13 February 2012 in France, the minutes of the workshop can be found here: http://www.enaee.eu/wp-assets-enaee/uploads/2012/03/CR-MINUTES-International-workshop-EUR-ACE-Feb-2012.pdf
516 http://www.enaee.eu/accredited-engineering-courses-html/
517 https://www.enaee.eu/eur-ace-system/standards-and-guidelines/

engineering degree programme which it has accredited. The key characteristics of the EUR-ACE® label include the following:

- It encompasses all engineering disciplines and profiles, is internationally recognised and facilitates both academic and professional mobility.
- It gives international value and recognition to engineering qualifications and is awarded to programmes which fulfil the programme outcome standards as specified in the EUR-ACE® Framework Standards.
- has created a quality system for accredited engineering degree programmes that share common objectives and outlooks.

Benefits for HEIs:

- It is an additional verification of high-quality engineering education– it meets the quality standards set by the engineering profession;
- It provides an incentive for prospective students to choose a EUR-ACE® labelled programme;
- It provides reliable information on the quality of First Cycle programmes for admission to Second Cycle programmes;
- It provides reliable information on the quality of Second Cycle programmes for admission to doctoral programmes.

Benefits for employers:

- Candidates' knowledge, understanding and practical capabilities meet international standards in engineering education;
- Consistency with recognised international educational standard descriptors such as the ECTS Diploma Supplement;
- Reliable verification of the high quality of the engineering degree programme of candidates, (above the generic minimum standards set by law), as well as relevance to the engineering profession.

Benefits for students & engineering graduates:

- Assurance that the EUR-ACE®-labelled programme meets high European and international standards and is recognised by employers in Europe;
- Facilitates application to EUR-ACE® Master and doctoral programmes in other Higher Education Institutions;
- In countries where the engineering profession is regulated, EUR-ACE®-labelled programmes meet the educational requirements for becoming a Registered or chartered engineer.
- The EUR-ACE® label facilitates graduate mobility as promoted by the EU Directive on Recognition of Professional Qualification.
- The EUR-ACE® label is the educational standard for the professional card as promoted by FEANI.
- FEANI automatically includes EUR-ACE® labelled programmes in its Index which lists educational requirements for the Eur Ing title.

Benefits for Accreditation Agencies:

- Certification of quality of accreditation agency according to European Standards and Guidelines for Quality Assurance in Higher Education in the European Higher Education Area (ESG) and employers' requirements;
- Integration into the European network of engineering professionals;
- Possibility of accrediting in other European countries and worldwide;
- Emphasises outcome-based accreditation of engineering programmes;
- Dialogue between ENAEE and other similar organisations such as the International

Engineering Alliance with the objective of facilitating worldwide mobility of engineers.

Special attention needs to be paid to **ensuring the compatibility with the European Quality Assurance Reference Framework for Vocational Education and Training (EQAVET)**[518]. As highlighted above, the EQAVET is a reference instrument designed to help the EU MS supervise the continuous improvement of their vocational education and training systems based on the commonly agreed references. The EQAVET aims, by building mutual trust between the VET systems, to make it easier for a country to accept and recognise the skills and competencies acquired by learners in different countries and learning environments. In fact, the EQAVET comprises a quality assurance and improvement cycle (planning, implementation, evaluation/assessment, review/revision) based on a selection of quality criteria, descriptors and indicators applicable to quality management at both VET-system and VET-provider levels.

6.4. Monitoring the evolving skill needs

In order to continuously monitor the evolving skill needs of the manufacturing domain, and to analyse the corresponding implications for education and training, a **dedicated Skills Observatory** could be created at the EU level. The Observatory could also be used for continuous tracing of the main workforce flows in manufacturing, as well as for monitoring changes in the gap in manufacturing-related skills from both the qualitative and quantitative perspectives.

The Observatory could systemise both the actual developments on the skills market and the forecasts for the coming years. It would thereby provide policy makers with a powerful knowledge base for designing effective programmes and measures with **an aim to fully realise the manufacturing potential in Europe**. Furthermore, besides mapping skills-related data, the Observatory could serve as a platform for further engagement of the community in developing policy recommendations.

A complementary direction for action implies developing **a pan-European online self-assessment tool** allowing students and workers to perform an assessment of their own Industry 4.0 skills, and make comparisons with others at the level of specific skills and qualifications (see Highlight 6-2 for a model example from Germany).

Highlight: Online Skills Check 4.0[519]

This new online tool called "Online Skills Check 4.0" developed by VDMA (The Mechanical Engineering Industry Association, Germany), gives both students and engineers at companies an idea of their own Industrie 4.0 skills. The tool provides information on each individual's own skills, offering a general self-assessment in terms of "need for significant qualification," "need for targeted qualification," "good outlook" or "excellent outlook". Furthermore, participants can conduct a comparison at the level of detailed skills and qualifications. The "Online Skills Check 4.0" is available at

518 https://www.eqavet.eu
519 Impuls Foundation (2019) "Impuls compact: Engineers for Industrie 4.0", VDMA (The Mechanical Engineering Industry Association), March 2019

www.ingenieure40-online-tool.vdma.org.

6.5. Supporting the professional development of educators and trainers

Finally, special attention needs to be paid to supporting the professional development of educators and trainers in an effective and systemised way. In that regard, the **Irish National Professional Development Framework** can be referenced as a good practice example that could be promoted at the EU level. Piloted in 2017, the framework addresses those who teach in higher education. The initiative, run by the National Forum for the Enhancement of Learning and Teaching in Higher Education, has already proved to be robust and impactful[520]. The Highlight below provides more information about the framework.

Highlight 6-3: The Irish National Professional Development Framework[521]

The framework incorporates both the informal conversations that staff have over coffee and the more formal accredited qualifications. It is developed to promote engagement among staff, enabling individuals to interpret it in their own context and to set big or small goals to meet their current development needs. It recognises that even those leadership positions need ongoing professional development opportunities to learn new skills and competencies at different stages in their career if they are to remain leaders in what is now a rapidly evolving and challenging teaching and learning environment.

The Irish Framework **puts the teacher at the core**, encouraging those who teach to reflect on their own 'self' as teacher and to think about how that influences their teaching practice. It also recognises that during their career, those teaching in higher education can have a number of professional identities, all requiring a different set of skills and competencies, and some that must be learned for the first time. It enables all those engaging with it to capture whether what they are now doing is new learning or a consolidation of existing learning, and it enables them to capture when they are mentoring another or taking a leadership role.

A digital domain based on **Ireland's Digital Skills Framework**[522] was included to provide a structure for higher education staff to develop their capacity to harness the potential of technology to enhance their teaching practice.

The Irish Framework focuses on engagement and recognition rather than accreditation, by stressing the importance for an individual to have career-long ongoing commitment with professional development. The Framework has no sense of hierarchy or linear progression to higher levels. It recognises that staff travel a number of horizontal and vertical pathways and often have several professional identities as they progress through their career. It has been included in the Higher Education Authority Performance Framework 2018-2020 for all Irish higher education institutions.

520 Maguire T. and Donnelly R. (2019) "Irish plan offers European roadmap to improve teaching", The World University Rankings, 5 March 2019
521 *Ibid*.
522 https://www.allaboardhe.ie/

Annex A: Key outcomes of expert workshops and the final conference

In total, six high-level expert workshops were organised in the context of this initiative. Each of the workshops had its own thematic orientation, with the first three workshops focussing on exploring the state-of-play and key challenges, and the other three workshops examining in detail the identified priorities, each time either for non-tertiary vocational education, Higher Education or on-the-job training[523]. The workshops served as a platform for collecting, testing and validating findings, and implied active engagement of all key stakeholder groups. Each workshop was attended by about 25 participants, representing all key stakeholder groups including education and training providers, industry, policy makers, supporting structures (such as industry associations, trade unions and cluster organisations) and learners. The workshops complemented multiple other forms of data collection, including extensive desk-research, online surveys, in-depth interviews and individual expert consultations. For each of the workshops, detailed workshop reports were developed, containing summaries of presentations and discussions. Below, the key highlights from each workshop are presented.

The first expert workshop on **"Aligning Advanced Manufacturing education and training with the 21st Century needs: Higher Education"**, held in Brussels on 12 June 2018, aimed to focus on new/alternative approaches to Higher Education, and specifically Bachelor and Master Programmes, in the field of AMT. It was concluded that there is a clear need to disseminate information on good practice examples among the educational institutions and companies in Europe. It is crucial to explore the replicability of good practices, as awareness raising is meant to serve only as the first step towards replicating/upscaling successful practices. There is also a need to look for financially sustainable business models for the educational offer such as, for example, sponsorship by companies that would like to have a tailor-made programme, alumni contributors, sublicensing etc. When it comes to relevant policy initiatives, they do not always have to be explicitly focussed on education and training to make an impact. Education and training elements can also be embedded into broader programmes, as a compulsory element.

The second expert workshop on **"Aligning on-the-job training in Advanced Manufacturing with the 21st Century needs"**, held in Brussels on 18 September 2018, focussed on the initiatives aiming to improve curricula/learning strategies for on-the-job training in the field of AMT. The workshop suggested that there is a need for a dedicated learning platform that would comprehensively combine a wide range of relevant courses with dedicated learning modules and link them to specific learning paths. Policy makers could play a role in facilitating the process of creating and maintaining such a platform. Special attention needs to be paid to new/updated job descriptions. Motivation of the learner is one of the key factors for successful upskilling/reskilling. The role of education and training is to cultivate motivation in learners.

The third expert workshop on **"Aligning Advanced Manufacturing education & training with the 21st Century needs: Non-tertiary vocational education"**, held in Brussels on 13 December 2018, focussed on the initiatives aiming to improve curricula/learning strategies for non-tertiary vocational education in the field of AMT. The workshop featured good practice examples and practical illustrations of the proposed solutions from VET providers. During the workshop, it was emphasised that the role of

523 For each of the categories, namely non-tertiary vocational education, Higher Education and on-the-job training, two dedicated workshops were organised (one during the first phase, and the other one during the second phase of the initiative)

schools, teachers and trainers needs to be reconsidered, with the learning ecosystem built around learners. The role of the schools is to teach the basics, that can be further built on by applying, for example, microlearning. There is also a high risk of developing unrealistic expectations regarding what students should know when they finish their studies. Since it is not possible to address every need, finding a good balance is key.

The fourth expert workshop on **"Reshaping Higher Education for Advanced Manufacturing: 21st Century Strategy, Collaboration Patterns and Learning Environment"**, held in Brussels on 5 March 2019, aimed to focus on the top three elements that require most substantial change (namely Strategy, Collaboration and Learning Environment) in the context of Higher Education for manufacturing. It was concluded that educational leadership is currently lacking. Without top-down coordination and vision, there will hardly be a systematic change. To succeed, universities need commitment from both higher and lower levels of the organisation. The curriculum needs to be reorganised around new student-centred and blended learning models, with problem-based projects across disciplines and together with stakeholders. Collaboration with industry and companies is essential to enhance learning outcomes, and to better align Higher Education with industry needs. Higher Education should be viewed as part of an educational chain or ecosystem. Finally, there is a need for a holistic approach with (improved) instruments to enhance Higher Education in Advanced Manufacturing and to improve the competitiveness of European industry.

The fifth expert workshop on **"Reshaping on-the-job training for Advanced Manufacturing: 21st Century Strategy, Collaboration Patterns and Learning Environment"**, held in Brussels on 7 May 2019, aimed to explore the three abovementioned elements in the context of manufacturing-related on-the-job training. During the workshop, it was emphasised that learning and working should not be viewed as two separate processes. Education cycles are increasingly getting shorter, and accreditation processes can hardly catch up. While learning & teaching factories represent promising solutions, a systematic approach is still missing. Co-creation and collaboration spaces prove to be effective, and there is a need for more initiatives supporting them. Technology is less relevant; it is what one does with it that matters.

The sixth (and final) expert workshop on **"Future-proofing Vocational Education for Manufacturing: Strategy, Collaboration Patterns and Learning Environment"**, held in Brussels on 17 September 2019, aimed to explore the three abovementioned elements in the context of manufacturing-related non-tertiary vocational education. Education and training for the new indusrial age require a holistic approach, keeping in mind the bigger picture and fitting into the overall lifelong learning trajectory. Students need much more than knowledge, they need to develop competencies, with the latter including also skills, values, attitudes and mind-sets. For curriculum goals and learning outcomes, we need to set ourselves free from conventional qualification frameworks and offer relevant personalised and personal learning. Learners should be viewed as change agents rather than passive receivers of education and training. Industry partners increasingly become educational, research and employment partners, by being engaged in the full student's learning experience, including curriculum strategy development. Different types of collaboration are needed, to ensure a multitude of experiential opportunities, including not only companies and educational institutions, but also peers, community and machines. Education and training for the VUCA world requires a Vision, Understanding, Commitment and Agility.

The final conference with a title "**Skills for Industry: Curriculum Guidelines 4.0**", held in Brussels on 26 November 2019, brought together the representatives of all key stakeholder groups, to discuss the key principles of the guidelines and agree on the next steps for their massive implementation across Europe. Big picture education, problem-based and student-centric approaches, experiential learning, human-robot interactions, evolving forms of collaboration with industry, peers and community - these and other relevant issues were actively addressed. The key outcomes of the discussion are as follows:

- The curriculum of today is the society of tomorrow.
- Students need to be prepared for the realities of lifelong learning, which implies providing them with specific tools, techniques and skills needed to continuously advance competencies.
- In order to create lifelong learners, they need to be given responsibility for their own learning process as early as possible.
- Europe needs effective learning eco-systems bringing all key stakeholder groups together for tackling key challenges and developing large-scale solutions.
- Automation can help us take the robot out of the human and enhance our truly human capabilities. Robots can enhance our learning experiences.
- There is a need to shift from a mind-set of human-machine interaction towards human-machine collaboration, and start developing collaboration skills with robots.
- New technologies do not destroy or create jobs, they influence specific tasks that human perform.
- Future-proof curricula imply developing techno-literacy or understanding of technology and the ability to use it.
- Education needs to be built around learning, not around teaching.
- The role of teachers is to support and facilitate the learning process, and learners need to be given a central role in the education and training processes.
- Curiosity is the main driver of learning, so we need to offer curiosity-driven curricula.
- Creative problem solving starts with creative problem spotting.
- Ergonomics goes far beyond the adjustable chairs, and learners need to be made aware about the effects of technology on their physical and mental health.
- Good leadership implies creating good conditions for people to perform.
- Health and well-being represent a collective responsibility.
- We should stop seeing learners just as users of education & training offers, and instead view them as humans with their own priorities, needs, behaviours and motivations.
- We need to be open to innovation, but we should not be obsessed with it.
- The importance of informal learning should not be underestimated. Informal learning is often not recognised, while recognition is key for learner’s motivation.

Annex B: Examples of new/alternative approaches towards education and training in KETs and AMT

Already today, a number of institutions across the world begin to change. New models of education are emerging.

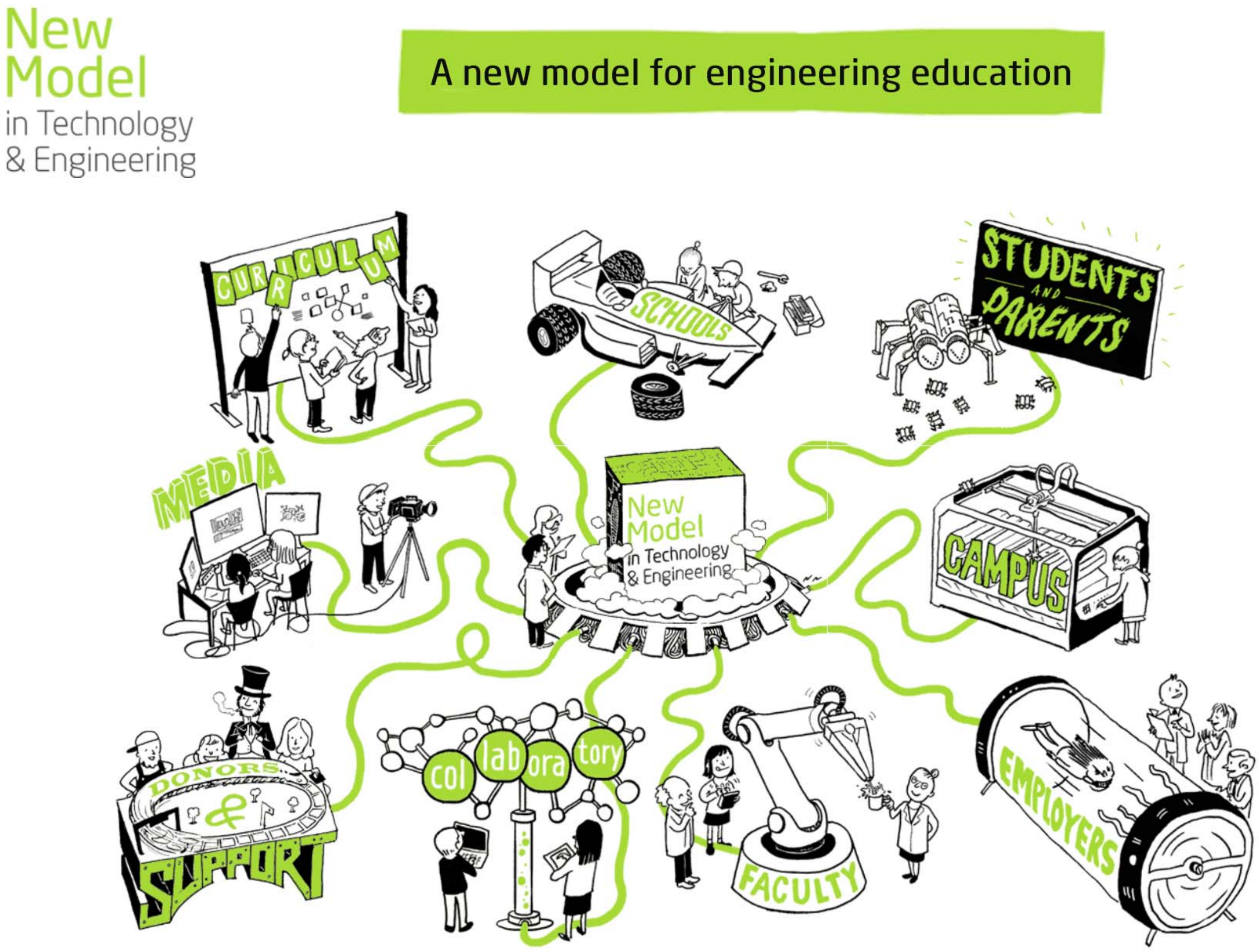


FIGURE B-1: A new model for engineering education by NMiTE[524]

Below we list some of the illustrative examples of the pioneers of these new educational approaches.

Olin College of Engineering (USA)[525]

Founded in 2002, Olin College of Engineering aims to radically change engineering education. It focusses on preparing students to become exemplary engineering innovators who recognise needs, design solutions and engage in creative enterprises for the good of the world. The entire curriculum is structured around the premise that engineering starts with people, with opportunities for multidisciplinary study and hands-on project work from the very start of the programme. Classes are organised in three interconnected themes: (1) Design and Entrepreneurship; (2) Modelling and Analysis; (3) Systems and Control, and are complemented by multidisciplinary classes that connect

524 http://nmite.org.uk/
525 http://www.olin.edu/

engineering, maths, and science to arts, humanities and entrepreneurship. Half of all Olin students are women. Major employers include Microsoft, Boeing, Google and Twitter.

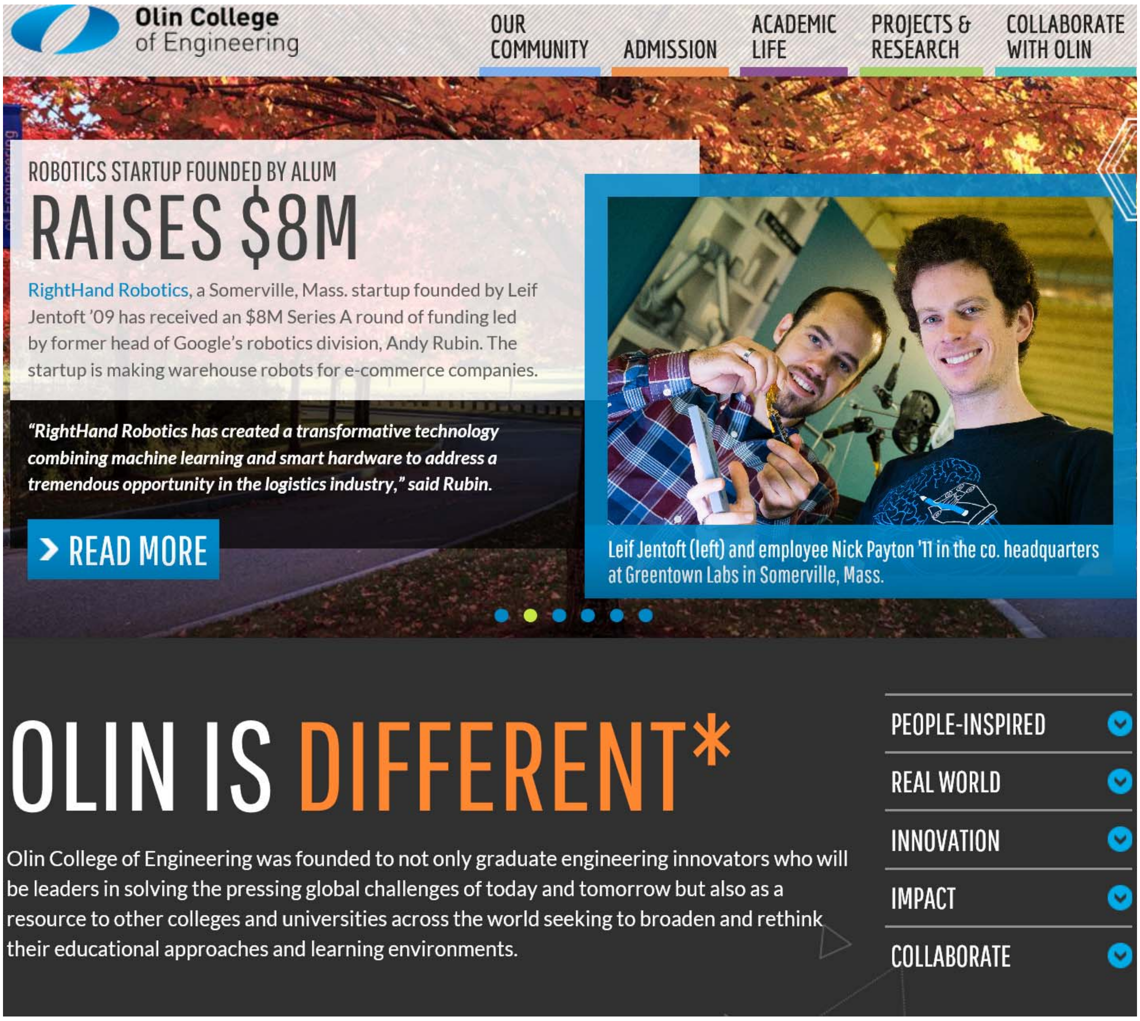


FIGURE B-2: Olin College of Engineering[526]

Aalborg University (Denmark)[527]

Since its founding in 1974, Aalborg has designed all of its courses around the principles of problem-based learning, synthesised into the Aalborg Model of Problem-Based Learning and applied across all subjects. In May 2014, the university opened a global Centre for Problem-Based Learning in Engineering Science and Sustainability, under the auspices of UNESCO.

A central objective of the Aalborg model is for students to develop social and academic skills simultaneously, and to develop collaboration skills that are seen as central to any kind of work in Denmark's knowledge economy. The model has extended across a global network of partner institutions, corporations and professional organisations. Students work in groups to complete specific projects. Projects are often offered in collaboration with Aalborg's business partners including Siemens, Nokia, Samsung, Texas Instruments and many others.

Below we provide detailed illustrative descriptions of the relevant Bachelor and Master programmes from Aalborg University.

526 http://www.olin.edu/discover-olin
527 http://www.ucpbl.net/

BSc. Manufacturing and Operations Engineering, Aalborg University (Denmark)

TABLE B-1: BSc. Manufacturing and Operations Engineering, Aalborg University (Denmark)

Nr	Item	Description
1.	***General characteristics***	**Title:** BSc. Manufacturing and Operations Engineering[528] **Education/training provider:** Aalborg University **Country:** Denmark **International orientation:** Partly. The course is taught in English **Duration:** 3 years **Target group:** Potential undergraduate students
2.	***Objectives and essence***	• **Key objectives:** The overall aim of the programme is to educate and equip bachelor engineers with innovation technology and understanding of state-of-art production technology and systems. The students will become a technology facilitators and developers as well as users. • **Expected learning outcomes:** Students are provided with a solid understanding of a) innovation technologies and b) production technology and systems within manufacturing, and the increased layer of servitization associated with the physical product. In addition to the technological aspects, this bachelor education will equip the students with the skills and competencies to a) oversee the entire process from the innovation to the production and service in terms of innovation technologies and production systems, b) communicate with end-users, both non-professional and professional users such as designers and engineers and c) to identify how to employ innovation technologies to facilitate, improve and integrate product, service and production development processes. The programme strives to give the students a comprehensive understanding of the important connection between a) business models, b) products and services, c) product and service innovation, d) productions systems, e) operations management and f) the actors and technologies involved in the productions and development processes. • **Brief description:** The programme is structured in modules and organized as a problem-based study. In the first five semesters, students will spend half of the study time on courses and course work while the other half will be spent doing a semester project in a small group – possibly in collaboration with an external organisation or institution. From the third semester you will have the opportunity to direct your focus in two different directions: "production of physical products" or "production of services". Most of the sixth semester will be spent on writing a Bachelor's project. • **Costs[529]:** There is no tuition fee for EU/EEA/Swiss students. Tuition fee for non-EU/EEA/Swiss students is DKK 92,500 (approx. EUR 12,400) for the full programme.
3.	***Relevance to addressing the new skill needs***	How the programme addresses: • **Multidisciplinary orientation**: The course is organized around manufacturing subjects and does not appear to have a multidisciplinary orientation. • **Dual/alternate education**: In projects students are encouraged to work with external partners and industry. However, based on the available information, the programme does not appear to facilitate this. • **Embedding non-technical courses:** Based on the available information, the course does not appear to embed non-technical courses. However, through an extensive use project work students are expected to develop

528 The course webpage and the curriculum description are used as sources unless otherwise stated. https://www.en.aau.dk/education/bachelor/manufacturing-operations-engineering/academic-content/ https://www.en.ses.aau.dk/digitalAssets/316/316507_moe-2017.pdf

529 https://www.en.aau.dk/education/apply/bachelor/finance-fees-bachelor/

Nr	Item	Description
		management and communication skills, etc. • **Problem-based/challenge driven learning:** Aalborg University is famous for its problem based learning where students work in teams on assignments often collaborating with an industrial partner. This study method is also called "The Aalborg Model for Problem Based Learning". The method is highly recognised internationally, and the university is host to a successful UNESCO chair in Problem Based Learning in Engineering Education and a Centre for PBL and Sustainability approved by UNESCO. • **Student-led learning:** Based on the available information, students appear to have a limited role in defining their curriculum. There is no available information on students' opportunity to influence the curricula in specific subjects.
4.	***Curriculum framework***	• **Subject or Discipline-Centred[530]:** The course is centred on a set of subjects, which combined deliver the course objective.
5.	***Delivery mechanisms***	• **In person delivery (classical delivery):** Teaching is done through use of lectures and project work, hinging on student presence.
6.	***Impact***	• No information was found.

MSc. Manufacturing Technology, Aalborg University (Denmark)

TABLE B-2: MSc. Manufacturing Technology, Aalborg University (Denmark)

Nr	Item	Description
1.	***General characteristics***	**Title:** MSc. Manufacturing Technology[531] **Education/training provider:** Aalborg University **Country:** Denmark **International orientation:** Partly. The course is taught in English, and students have the opportunity to do part of their studies abroad. **Duration: 2** years **Target group:** Potential graduate students with completed BSc. in relevant subjects.
2.	***Objectives and essence***	• **Key objectives:** The MSc programme in Manufacturing Technology aims at providing graduates with competencies to solve complex production-related problems and is designed to develop both theoretical understanding and practical experience. The programme particularly focusses on preparing the students for Industry 4.0. • **Expected learning outcomes:** The programme focuses on design, development and implementation of products, manufacturing and control systems; primarily in relation to development, planning and implementation of industrial production. • **Brief description:** The programme is structured in modules and organized as a problem-based study. The programme is structured giving the graduate the opportunity to specialise within specific areas; e.g. virtual product- and process development, material- and process technology and operation and robot technology. During the programme students will experiment in the university's smart lab. The 3rd semester offers different ways of organisation – depending on the student's choice of content; traditional project work at Aalborg University, study visit at an educational institution in Denmark or abroad, voluntary traineeship with project work at a company in Denmark or abroad, or a semester programme that comprises cross-disciplinary programme elements

530 The curriculum is organised around separate, specific subjects or disciplines. Based on the methodology of ABC Curriculum Resources, available at: http://gototheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles

531 The course webpage and the curriculum description are used as sources unless otherwise stated. https://www.en.aau.dk/education/master/manufacturing-technology https://www.en.ses.aau.dk/digitalAssets/316/316496_vt-25.4.17.pdf

Nr	Item	Description
		composed by the student. • **Costs[532]:** There is no tuition fee for EU/EEA/Swiss students. Tuition fee for non-EU/EEA/Swiss students is DKK 92,500 (approx. EUR 12,400) for the full programme.
3.	***Relevance to addressing the new skill needs***	How the programme addresses: • **Multidisciplinary orientation**: The course is organized around manufacturing subjects and does not appear to have a multidisciplinary orientation. • **Dual/alternate education**: In projects students are encouraged to work with external partners and industry. In additions, students can choose to spend their 3rd semester working with a company in Denmark or abroad, or to participate in a cross-disciplinary semester programme. • **Embedding non-technical courses:** Based on the available information, the course does not appear to embed non-technical courses. However, through an extensive use project work students are expected to develop management and communication skills, etc. • **Problem-based/challenge driven learning:** Aalborg University is famous for its problem based learning where students work in teams on assignments often collaborating with an industrial partner. This study method is also called "The Aalborg Model for Problem Based Learning". The method is highly recognised internationally, and the university is host to a successful UNESCO chair in Problem Based Learning in Engineering Education and a Centre for PBL and Sustainability approved by UNESCO. • **Student-led learning:** Based on the available information, students appear to have a limited role in defining their curriculum. There is no available information on students' opportunity to influence the curricula in specific subjects.
4.	***Curriculum framework***	• **Subject or Discipline-Centred[533]:** The course is centred on a set of subjects, which combined deliver the course objective.
5.	***Delivery mechanisms***	• **In person delivery (classical delivery):** Teaching is done through use of lectures, lab experimentation and project work, hinging on student presence.
6.	***Impact***	• No information was found.

Singapore University of Technology and Design (Singapore)[534]

Singapore University of Technology and Design was created in collaboration with MIT, with faculty and students working jointly to design an undergraduate curriculum with a focus on design and cutting-edge opportunities. The curriculum is built around the idea of the Big-D (for Design), which emphasises the experiential learning. Students also have to complete a capstone group project, often working in mixed groups from different pillars. Groups work with businesses or design their own products. All students also have an opportunity to engage in internships during their studies, with major companies including Google, Microsoft, IBM, Nestle and Rolls-Royce.

532 https://www.en.aau.dk/education/apply/master/finance-fees-master/#t295772
533 The curriculum is organised around separate, specific subjects or disciplines. Based on the methodology of ABC Curriculum Resources, available at: http://gototheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles
534 http://www.sutd.edu.sg/

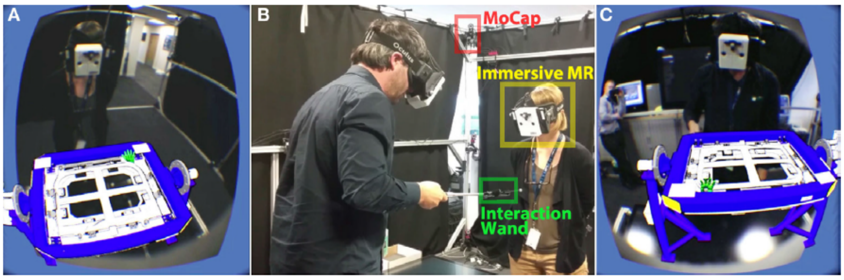
NMiTE (United Kingdom)[535]

In 2018, New Model in Technology and Engineering (NMiTE) will launch a new British university aiming to meet the needs of, among others, the advanced manufacturing and smart living sectors. The curriculum is being designed in collaboration with industry and academic partners (including Olin College of Engineering) and will use interdisciplinary and problem-based approaches to deliver curriculum content. All students will be required to study humanities, design and social science topics along with their core content and will be given mandatory 6-12 month work placements during their studies. The curriculum design includes rewards for innovative teachers and will incentivise staff to create 'safe to fail' environments[536].

All these and multiple other initiatives have been created also as a source of inspiration for other colleges and universities across the world, seeking to broaden and rethink their educational approaches and training environments.

eventLAB[537]: Augmented reality for Advanced Manufacturing training (Spain)

EventLAB, in close cooperation with Airbus Group Innovations (UK), University of Barcelona (Spain), Manufacturing Informatics Centre of Cranfield University (UK), and University College London (UK), developed a mixed reality setup allowing for real-time collaborative interactions and simulated conventional forms of training for the manufacturing environment538.



| **Mixed reality setup. (A)** Trainer's view, see-through with the virtual assembly jig. **(B)** Laboratory equipped with 24 motion capture cameras, and two participants wearing the mixed reality setups set for collaboration: the trainer is carrying the interaction wand while the second person observes the operation **(C)**. Participant's view. The Interaction wand in is represented by the green actuator.

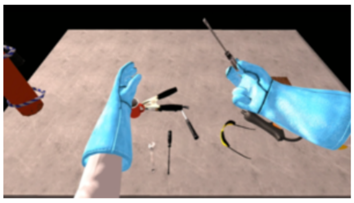
FIGURE B-3: Mixed reality setup for Advanced Manufacturing training[539]

The augmented reality training tools can deliver a high degree of interactive realism that walks trainees through a sequential process using actual 3D images of real-world environments. Trainees can engage with a fully realised dimensional representation of an assembly line, for example, as well as the precise layout of the racks, tools and materials around the line[540].

535 http://nmite.org.uk/
536 NESTA (2016) "The challenge-driven university: how real-life problems can fuel learning", by Mulgan G. and Townsley O.
537 http://www.event-lab.org/
538 Gonzalez-Franco M. et al. (2017) "Immersive mixed reality for manufacturing training", Frontiers in Robotics and AI, published on 16 February 2017
539 Gonzalez-Franco M. et al. (2017) "Immersive mixed reality for manufacturing training", Frontiers in Robotics and AI, published on 16 February 2017
540 http://lightguidesys.com/blog/augmented-reality-training-tools-manufacturers/

Such systems can record hand position, and sequencing, ensure trainees use the correct tools and the right number of parts, and can even facilitate independent training and certification by giving users the option to complete tasks without computer guidance[541].

EIT Digital: new industrial virtual reality training tool[542] (EU)



Gleechi - Virtual Grasp

EIT Digital is launching an Innovation Activity to develop a virtual reality (VR) training tool to help improve safety, reduce downtime and save costs for European industries. Named the "Handcode project", the work is to be carried out by two EIT Digital partners in Sweden – RISE SICS Västerås and Gleechi alongside The French Alternative Energies and Atomic Energy Commission (CEA) in France. The scenarios in three-dimensional environments enable training without risk to the trainee and at minimum expense. The platform will handle standard ways of interaction for training, such as using regular tools, pulling levers and pushing buttons. Pilots with manufacturing companies are planned for later this year before a commercial roll-out in 2018.

Festo Didactic[543]: state-of-the-art technical and non-technical training for Advanced Manufacturing (Germany, USA, Italy, China)

Festo Didactic is the world-leading provider of equipment and solutions for technical education. It provides higher education institutes and companies with access to the technology and applications of Industry 4.0. The offered training refers to networking, PLC programming, drive technology, sensor technology, safety technology, robotics, assembly, value stream analysis and optimisation etc., as well as a range of non-technical courses (e.g., leadership, communication, project management) tailored to the needs of Advanced Manufacturing.

ELIAS project544: Towards modern work and production systems (Germany)

ELIAS is a collaborative project of the Federal Ministry of Education and Research (BMBF), with a goal of designing modern work and production systems to encourage learning. The abbreviation stands for "Engineering and Mainstreaming of Learning-based Industrial Work Systems for Industrie 4.0". The project developed a model for the design of company learning solutions for work-based training. It also produced a catalogue of instruments and forms of learning. These learning solutions are now being tested in practice by SMEs, for example, Zwiesel Kristallglas, in the course of their transition from Industrie 3.0 to Industrie 4.0.

Online training for KETs and AMT

Online training opportunities for KETs and AMT rapidly gain popularity, for example, through MOOC platforms, such as Coursera[545], edX[546], Udacity[547], and Futurelearn[548]. Courses in these platforms are typically designed around video lectures with in-video-

541 http://lightguidesys.com/blog/augmented-reality-training-tools-manufacturers/
542 https://www.eitdigital.eu/newsroom/news/article/eit-digital-to-develop-new-industrial-virtual-reality-training-tool/
543 https://www.festo-didactic.com/int-en/
544 http://www.plattform-i40.de/I40/Redaktion/EN/Downloads/Publikation/digital-transformation-training.pdf;jsessionid=54D99194561981FACDF848B3D273B616?__blob=publicationFile&v=3
545 https://www.coursera.org/
546 https://www.edx.org/
547 https://www.udacity.com/
548 https://www.futurelearn.com/

quizzes, discussion boards, and different types of assignments and tests. Both regular online courses and MOOCs can be used in conjunction with face-to-face teaching to create a blended learning course[549].

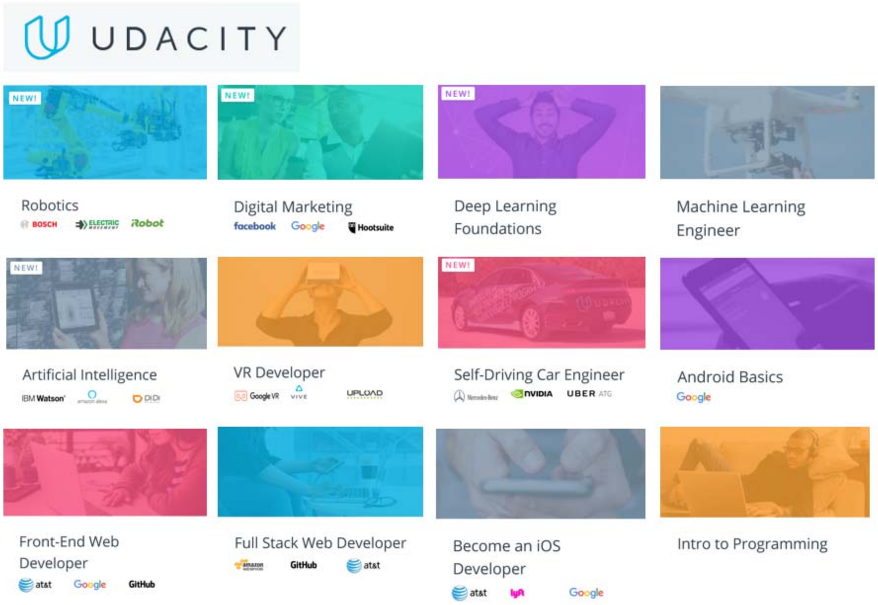


FIGURE B-4: Illustrative examples of available ICT- and KETs-related courses on Udacity ("nanodegree")[550]

…and many more…

549 http://www.elearning.dtu.dk/LEARN/Online-Courses-and-MOOCs
550 https://www.udacity.com/nanodegree

Annex C: Key technological developments in AMT

In this Annex, we elaborate on the technological developments in each of the manufacturing areas identified in Figure 2-2.

C.1.1. Pre-production & Planning

Before products are even scheduled for manufacture, they may be prototyped and refined iteratively to satisfaction. Finalised designs and required production volumes would point to defined quantities of input materials and resources to be procured. The workforce required for the production cycle should be trained and available – supported by necessary equipment and information where required. The Pre-production & Planning stage is crucial to meeting bottom-line targets in a time-critical and capital-intensive setting, and thus technology is increasingly playing an important role in improving processes in this domain.

Research, Design & Development

Depending on the industry, research and development (R&D) and product design may be critical. The introduction of these technologies and techniques may speed up development, reduce costs of iterative refinement, allow for better visualisations that are understandable by experts and non-experts alike, and even facilitate invention of new configurations that may not have been possible before. Within this context, the following technologies and techniques can be used[551,552]:

- Design thinking workshops and innovation sprints to identify and cater to user demands and requirements;
- Computer-aided design (CAD) tools for prototype and iterate on new product designs;
- 3D printing to develop proof of concepts and test aesthetic/mechanical qualities;
- Virtual, augmented or mixed reality (VR/AR/MR) headsets to visualise products at human scale;
- Advanced data analytics to process extensive documentation (e.g. material/substance properties databases);
- Pilot experimentation with new components or materials;
- Robotics to automate trial-and-error processes (such as high-throughput chemicals testing);
- Materials simulation software to develop at nanoscale precision (such as semiconductor and chip design);

Implications for curriculum requirements: any curriculum must provide the workforce with the skills to not only use the relevant software and hardware, but also

551 PwC analysis incorporating multiple expert sources
552 CBInsights (2018) "Future Factory: How Technology Is Transforming Manufacturing". Retrieved October 15, 2018

train the workforce to identify potentially new opportunities for innovation and improvement across the product portfolio. Since no single employee can effectively master all the skills necessary (nor is this desirable), the workforce must also be able to collaborate across territories, cultures, languages and competencies.

Resource Planning & Sourcing

Once the blueprints for a specific product have been fixed, there is a detailed procurement process to plan and order the volume of specific parts and components required to mass-produce the product. This includes conducting market research to determine product pricing, assembling a list of parts, components and specifications and estimate costs, drawing contracts with multiple suppliers across international borders and generating regular demand forecasts to optimise production volume and inventory management of both input supply and finished product output. Within this context, the following technologies may be incorporated[553,554,555,556]:

- Manufacturing process simulations to optimise production volume and anticipate bottlenecks;
- 3D printing of parts and components *in situ* or *en route* where possible to minimise supply chain complexity;
- Complex unified, real-time enterprise resource planning (ERP) software, possibly incorporating blockchain, for tracking material procurement and preserving transparency of provenance;
- Automated and standardised workflows for contract management across hundreds (if not thousands) of suppliers and partners yielding higher efficiency, lower risk and more transparency.

Implications for curriculum requirements: the lean manufacturing paradigm will continue to drive demand for advanced manufacturing, with its holistic emphasis on high productivity and minimal waste. Achieving this goal requires human discipline and within complex value chains, a healthy dose of technological assistance. Curriculum should train workforce in identifying areas for improvement – both quick wins and fundamental changes – and utilising the right technologies to achieve these improvements. Communication about these opportunities should also flow both top-down and bottom-up and thus company culture needs to change and accommodate this. A certain level of agility is expected to capitalise on these opportunities in a matter of weeks rather than months or years – and thus training should communicate how such changes can be realised factory-wide in short periods of time.

Labour augmentation and management

The role of humans in Advanced Manufacturing will change from primarily manual labour to more tactical planning and specialised processes, with the other tasks being taken by machines. While lights-out manufacturing – completely automated factories where humans are not required at all - is possible in theory, many manufacturers are realising there are benefits to blended workforces where robots assist humans and humans assist

553 PwC analysis incorporating multiple expert sources
554 CBInsights. (2018). Future Factory: How Technology Is Transforming Manufacturing. Retrieved October 15, 2018
555 Vaseekaran, A. (2018). The Critical And Evolving Role Of Contract Management In Digital Transformations. Retrieved October 15, 2018
556 De Backer, K., Mercker, B., Moder, M., & Spiller, P. (2017). Purchasing power: Lean management creates new value in procurement. Retrieved October 15, 2018

robots to supercharge productivity[557]. In this context, the following technologies may be incorporated into the manufacturing environment[558,559,560]:

- Labour management systems to capture worker activity data and optimise processes both day-to-day and long-term;
- Real-time dashboards to monitor factory staffing and activity;
- Cameras, scanners and other sensors embedded in the production line to provide timely feedback and allowing supervisors to oversee factory remotely;
- Augmented reality headsets to help workers see relevant information in a timely manner, recall steps in complex processes on-demand, provide extended situational awareness in dangerous conditions, and enhance precision work;
- Mobile devices may also provide augmented intelligence and capabilities on-demand – such as wrist-mounted screen for displaying relevant details and recording observations on-the-spot;
- Embedded sensors can measure for inefficiencies in lean production systems (down to distance of trash can from seat);
- Wearable technologies that can detect level and strain of activity, suggest reminders for proper posture and schedule breaks;
- Exoskeletons to reduce the physical toll of repetitive work and help bear larger loads over longer distances;
- Collaborative mobile robots (or cobots) to perform repetitive tasks and be trained on-the-fly without programming required.

Implications for curriculum requirements: Advanced Manufacturing will fundamentally alter the role of humans in the manufacturing environment – and hence curriculum must familiarise workers with their "silver collar" co-workers i.e. automation and AI[561]. Workers should not only understand what digital technologies can do, but also what they cannot do – in order to compensate in complementary way. Moreover, workers should be made aware of potential risks – such as data privacy breaches, cybersecurity, anomalous data, etc. – so that they can keep a look out to avoid those. Finally, workers should be trained in the maintenance and/or repair of the automation surround them, and where needed, briefed on human-only tasks in emergency situations.

C.1.2. Production & Logistics

When it comes to the manufacturing itself, it is necessary to consider the transformation process of input materials into final products, and beyond that how these products are eventually distributed via various channels into the market and into the hands of clients and customers. This is especially complex because approaches like just-in-time production, which optimises for high throughput but low idle inventory, requires a

557 CBInsights. (2018). Future Factory: How Technology Is Transforming Manufacturing. Retrieved October 15, 2018
558 PwC analysis incorporating multiple expert sources
559 CBInsights. (2018). Future Factory: How Technology Is Transforming Manufacturing. Retrieved October 15, 2018
560 McCrea, B. (2017). Labor Management Systems Get "Smart." Retrieved October 15, 2018
561 Kayser, H., Ey, M., Gerdemann, P., Kuz, S., Muller, J., Navrade, F., Sayed, M. (2017). Accelerating Labour Market Transformation. Retrieved October 15, 2018

seamless and smooth-running post-production supply chain to fully realise the efficiency benefits. Here, technological advances can provide many benefits.

Machining, Production & Assembly

Manufacturing in the past often featured repetitive, tedious and even dangerous activities, and these tasks are increasingly being automated. The benefits from automation are not just increased efficiency and productivity, but also higher safety and flexibility. Cyber-physical systems like industrial robotics and 3D printing are getting cheaper, safer and often work in tandem with human tasks rather than completely independently[562]. In the future, production will become even more agile and customisable – requiring even more flexibility in a way that would challenge typical mass manufacturing paradigms. The following technologies are expected to play a role[563,564,565]:

- Heavy-duty industrial robotics for dangerous and high speed activities;
- Autonomous ground vehicles (driverless trolleys) to transport items for point to point without human supervision;
- Modular equipment that allows production to be flexible for customisation – for example, products may be designed to be assembled from smaller building blocks that may be arranged in various configurations instead of machined as a single artefact, or robotic arms may have switchable end-effectors depending on the requirements;
- Supervisory control and data acquisition (SCADA) systems and human-machine interfaces providing rich monitoring data for operations analysts;
- Industrial equipment may be custom-made on-demand for specialised tooling;
- Industrial cobots on the factory floor assisting humans on an ad-hoc basis; these robots may be "trained" on the fly with no programming required, performing tasks like drilling, sorting and packaging;
- Lights-out manufacturing where humans are not even needed to be present, and the machines don't necessarily need lights or even heating/cooling;
- Smaller and targeted batch production going hand-in-hand with hyper-personalised business models;
- High density of embedded sensors to recreate "digital twins" of the manufacturing environment;
- Augmented reality headsets to provide situational awareness and on-demand information in a hands-free manner;
- 3D printing (additive manufacturing) for custom designs, especially "no assembly required";

562 CBInsights. (2018). Future Factory: How Technology Is Transforming Manufacturing. Retrieved October 15, 2018
563 PwC analysis incorporating multiple expert sources
564 Autodesk. (2018). Autodesk Generative Design. Retrieved October 15, 2018
565 CBInsights. (2018). Future Factory: How Technology Is Transforming Manufacturing. Retrieved October 15, 2018

- Computer Numerical Control (CNC) machines for automated subtractive manufacturing;
- Computer vision to spot defects;
- Algorithmic design that can generate substitute shapes with the same material and mechanical properties but less material usage overall;
- Exoskeleton support for humans working with heavy loads or repetitive tasks;
- Predictive maintenance to minimize downtime;
- Cybersecurity to preserve integrity of processes and prevent sabotage.

Implications for curriculum requirements: the production line of the future will include less manual labour and more emphasis on speed, customisation and flexibility. Workers will regularly interface with real-time data visualisations and complex software on a variety of devices, while also switching frequently to performing some manual tasks. Workers on the factory floor will generally have more supervisory roles to guide automation. There is also a significant risk of cybersecurity threats in an increasingly digitised factory, and workers will need to be aware if not capable of preventing and dealing with various scenarios of cyberattacks.

Given the expected high robot density, workers will require training on how to work alongside "silver collar" workers, i.e. automation and AI[566]. This is not just a question of establishing familiarity but also vital for safety and quality reasons. Workers should be able to critically analyse inputs and outputs coming from digitized processes with a view on what machines are good at and where they are likely to fail. Management would also require training to manage expectations of productivity – even if machine increased speed and decrease errors in individual automated processes, the overall flow may still be bottlenecked by upstream/downstream human activities. Modular manufacturing also requires better planning.

Moreover, there are cultural aspects to learning to work with automation and AI. Unconscious biases like "uncanny valley" have been reported – wherein artificial objects that imitate lifelike behaviour may induce revulsion rather than fascination – and can be expected in an increasingly digitised factory setting as well[567]. As such, curriculum should instil a deeper sense of familiarity towards intelligent machines.

Supply Chain Management

Products become increasingly complex requiring thousands of parts and components, each sourced from a multitude of suppliers. Moreover, finished products are also distributed internationally in various quantities and volumes with high frequency. Keeping track of this complexity is crucial to reduce risks, and anticipate bottlenecks. Hence technology is increasingly entering the supply chain management aspect of manufacturing. Here are some examples of how technology may be incorporated[568,569,570]:

566 Kayser, H., Ey, M., Gerdemann, P., Kuz, S., Muller, J., Navrade, F., Sayed, M. (2017). Accelerating Labour Market Transformation. Retrieved October 15, 2018
567 The Economist. (2012). Mapping the uncanny valley. Retrieved October 15, 2018
568 PwC analysis incorporating multiple expert sources
569 CBInsights. (2018) "Future Factory: How Technology Is Transforming Manufacturing". Retrieved October 15, 2018
570 Pettey, C. (2018) "Gartner Top 8 Supply Chain Technology Trends for 2018". Retrieved October 15, 2018

- Complex, real-time and unified ERP systems to manage inputs and outputs across thousands of suppliers, vendors, partners and clients;
- IoT tags, sensors and systems for tagging and tracking shipments;
- Blockchains to preserve provenance and process information on shipments across the value chain, from raw materials to finished products (and beyond), in a tamper-proof way;
- Payment technologies to facilitate secure and frictionless clearing and settlements;
- Predictive analytics to anticipate and resolve bottlenecks;
- Artificial intelligence and advanced analytics to assist in decision making, automate geospatial routing and optimise for emissions reduction;
- Robotic process automation for automatically handling "paperwork" alongside physical movement of shipments;
- End-to-end transparency in supply chain through digitisation;
- Decentralised supply chains;
- Cybersecurity to preserve integrity and prevent sabotage.

Implications for curriculum design: the opportunities for digitisation within the supply chain domain are plenty, with obvious benefits. Employees will increasingly need to interface with multiple platforms to track and maintain proper information flows alongside product flows. As such, employees should be able to work with data and have analytical capabilities to make data-driven decisions. More than that, workers will benefit from data analytics experience to realise more structural efficiency gains. Employees should also be trained and equipped with the know-how to identify and realise quick wins in terms of value-adding information capture. As sustainability and emissions reduction become increasingly important, workers will require the skills and autonomy to identify and implement measures to maximise efficiency. Finally, supply chain is also a key area where cyberattacks are likely, and at least a portion of the workforce should be trained to anticipate, prevent and/or deal with cybersecurity issues.

Warehousing & Transport

Once finished products exit the production line, they are either being transported or temporarily warehoused before reaching customers. The speed of storage and recall is critical, and the growing emphasis on emissions reduction requires new technologies like electric mobility and optimised routing. The following are examples of how technologies are impacting the warehousing and transportation processes[571,572,573]:

- Lights-out warehousing where there is no need for humans to store and retrieve items;
- Robotics for tasks like picking, sorting and palletising;

571 PwC analysis incorporating multiple expert sources

572 CBInsights. (2018) "Future Factory: How Technology Is Transforming Manufacturing". Retrieved October 15, 2018

573 RCS Logistics. (n.d.) "7 Ways in Which Technology Has Shaped the Warehousing and Distribution Industry". Retrieved October 15, 2018

- IoT tags, sensors and systems for tagging and tracking shipments;
- Electric mobility to reduce net emissions from transportation;
- Autonomous vehicles within warehouses and on the roads to ultimately remove the need for humans to simply transport items from point to point;
- Real-time data visualisation to track shipments precisely and accurately;
- Decentralised and last-mile deliveries via drone;
- Automated scanning and recording of items using computer vision;
- Augmented reality headsets to provide situational awareness and relevant information in a hands-free manner;
- Exoskeletons to assist workers in repetitive or dangerous tasks;
- Artificial Intelligence and advanced analytics to assist in decision making, automate geospatial routing and optimise for emissions reduction;
- Blockchain for tamper-proof recording of provenance and transit information in compliance with international border crossing requirements;
- Scheduling and sharing warehouses and/or fleets to minimise costs and risks.

Implications for curriculum design: workers will increasingly work with real-time data platforms and have to be trained in making critical and analytical data-driven decisions. Within warehouses, workers will require training and familiarity to work alongside automation. Safety training will also be important in this fast-moving environment.

C.1.3. Monitoring & Control

As the manufacturing environment gets increasingly digitised, there will be a proliferation of sensors and data streams with the primary objective being to monitor and control critical variables in real-time. Doing so will not only enhance efficiency and productivity, but also quality, safety and compliance.

Operations, Maintenance & Continuous Improvement

Factories of the future will be complex cyber-physical entities with only minimal need for human intervention. The goal according to lean manufacturing is to reach 100% overall equipment effectiveness (OEE) – which is a measure of actual performance against theoretical production capacity[574]. For reference, the average factory has an OEE of about 60% whereas world-class manufacturing sites have an OEE of close to 85%[575]. Therefore, optimising this metric can best be achieved by incorporating more technology in the manufacturing environment, such as[576,577]:

574 CBInsights. (2018) "Future Factory: How Technology Is Transforming Manufacturing". Retrieved October 15, 2018
575 CBInsights. (2018) "Future Factory: How Technology Is Transforming Manufacturing". Retrieved October 15, 2018
576 PwC analysis incorporating multiple expert sources
577 CBInsights. (2018) "Future Factory: How Technology Is Transforming Manufacturing". Retrieved October 15, 2018

- High density of IoT sensors and actuators combined with real-time synthesis of data streams to create “digital twins”;
- Manufacturing process simulations to optimise production volume and anticipate bottlenecks;
- Enhancing worker productivity and minimising errors using augmented reality headsets to provide situational awareness and hands-free relevant information on-demand;
- Automated scanning and recording of items using computer vision;
- Predictive maintenance to minimize downtime;
- Connected manufacturing equipment that “talk to one another”;
- Supervisory control and data acquisition (SCADA) systems and human-machine interfaces providing rich monitoring data for operations analysts;
- Edge intelligence providing decentralised decision-making and automation potential based on incoming sensor data; saves data bandwidth and may reduce cyberattack exposure;
- Cybersecurity to preserve integrity and prevent sabotage;
- Blockchains for tamper-proof logging of machine and sensor data;
- Advanced data analytics for optimisation and continuous improvement.

Implications for curriculum design: as workers perform less manual labour in digitised factories, this area will require more manpower to perform – aided by custom software and artificial intelligence. Workers involved in these processes must be trained in advanced data analytics and processing of big data. They must also be comfortable with working with both hardware and software (IoT sensors, cameras, computer vision algorithms, cloud machine learning, blockchain etc.) to generate positive outcomes. Finally, this is a critical area that will potentially be exposed to cyberattacks so workers must be trained in cybersecurity hygiene, detection and response.

Quality, Risk & Compliance

Quality assurance will increasingly be embedded in the codebase. Moreover, robotics and automation may remove risks such as those due to human error, while introducing new risks to be assessed and managed such as those stemming from equipment malfunction or cyberattacks. Moreover, digitised manufacturing environments have the opportunity to embed compliance specifications within the codebase. One of the biggest benefits from digitizing the manufacturing environment will be increased transparency not only for companies and regulators, but also ultimately to clients and consumers as well. Technology may be incorporated in the following ways[578,579,580]:

- High density of IoT sensors and actuators combined with real-time synthesis of data streams to create “digital twins”;

578 PwC analysis incorporating multiple expert sources

579 CBInsights. (2018) “Future Factory: How Technology Is Transforming Manufacturing”. Retrieved October 15

580 Pilgrim Quality (2018) “Smart Quality Management: The Impact of Industry 4.0 on QMS”. Retrieved October 15, 2018

- Predictive maintenance to minimize downtime and prevent accidents;
- Blockchains for tamper-proof logging of machine and sensor data;
- Cybersecurity to preserve integrity and prevent sabotage;
- Real-time quality control as opposed to *post hoc* quality checks;
- Risk assessment and management simplified by connected equipment and data streams to directly process and evaluate performance data.

Implications for curriculum design: workers involved in these processes must be trained in advanced data analytics and processing of big data. If involved with the installation and implementation of codebase and equipment responsible for production, they must also be trained in context of cybersecurity by design, and be able to output clean and readable code as well test, find and fix potential bugs – as their input is critical for the manufacturing environment to achieve zero incidents and zero defects.

Health, Safety & Environment

Not only can automation reduce the need for humans being exposed to unsafe or dangerous activities/environments, technology can also actively reduce and prevent injuries or casualties across the manufacturing environment. Moreover, human safety is paramount not just within the fences of the factory, but also the wider public. In this context, technology can also support environmental monitoring and process by-products to minimise downstream health effects. The following list provides examples of how technology may be incorporated in this area[581,582]:

- Augmented reality headsets to provide situational awareness and relevant information in a hands-free manner;
- Virtual reality and immersive simulations to train workers on critical actions to undertake in emergency scenarios;
- Exoskeletons to assist workers in repetitive or dangerous tasks;
- Collaborative mobile robots (or cobots) to perform repetitive tasks and be trained on-the-fly without programming required;
- Cameras, scanners and other sensors embedded in the production line to provide timely feedback and allowing supervisors to oversee factory remotely;
- High density of IoT sensors and actuators combined with real-time synthesis of data streams to create "digital twins" – with specific features for health and safety;
- Computer vision and artificial intelligence to monitor critical areas to prevent accidents (similar to a "traffic policeman");
- Wearable technologies that can detect level and strain of activity, suggest reminders for proper posture and schedule breaks;

581 PwC analysis incorporating multiple expert sources
582 Minturn, A. (2017) "Safety first: How Industry 4.0 can optimise safety". Retrieved October 15, 2018

- Environmental sensors monitoring heat, sound, radiation, chemical leaks etc. to alert workers to evacuate when unsafe levels are detected;
- Data-driven and real-time risk assessment allows for strategic as well as tactical safety monitoring;
- Blockchains for tamper-proof logging of machine and sensor data – especially fumes, emissions and composition of waste streams.

Implications for curriculum design: workers involved in designing or implementing health, safety and environment (HSE) systems must be able to incorporate sensors to detect critical signals, program the require logic to meet or exceed compliance standards and be able to retrieve the data for subsequent analysis. Systems and software should be simple enough for workers on the production line to use without significant changes to their daily routine. Workers should be trained not to tamper with HSE equipment and sensors, and regularly check if the equipment is functioning as intended.

C.1.4. Emerging Paradigms

The following themes and processes are gaining relevance and popularity, especially in response to the new requirements of the increasingly digitized manufacturing environment. Cyberattacks are a significant risk to any digital infrastructure and can deal severe damage to industrial value chains without ample cybersecurity to anticipate, detect and mitigate the damage. Products are increasingly augmented with software and intelligence, which subsequently allow products to be supported over the product lifetime via value-adding services – this is known as the Product-Service System paradigm. Advanced manufacturing must increasingly incorporate support systems to deliver digital products and services to their customers. Finally, the growing importance of sustainability and circular economy are becoming clear in light of environmental and ecological threats like climate change. Hence this is also an area that advanced manufacturing must accommodate in future.

Cybersecurity

With digital factories featuring hundreds (if not more) of connected equipment, the cyber-exposure is quite high and the potential damage from a breach could be devastating, with many ripple effects in the upstream and downstream supply chain as well[583]. As such, cybersecurity strategies should be implemented ground-up and by design. The goal is to be secure, vigilant and resilient. It is critical to note here that cybersecurity is not just a technological vulnerability and that even the strongest encryption system is vulnerable to human error such as responding to phishing emails or carelessly exposing login details in public. That said, the following technologies can help within the context of a comprehensive cybersecurity strategy[584,585]:

- Blockchains for tamper-proof logging of network connections;
- Real-time network monitoring with artificial intelligence to detect fraudulent behaviour or suspicious activity within the network;
- Extensive ethical hacking and/or bug-testing to minimise cyberattack vulnerabilities;

583 Waslo, R., Lewis, T., Hajj, R., & Carton, R. (2017) "Industry 4.0 and cybersecurity". Retrieved October 15, 2018
584 PwC analysis incorporating multiple expert sources
585 Waslo, R., Lewis, T., Hajj, R., & Carton, R. (2017) "Industry 4.0 and cybersecurity". Retrieved October 15, 2018

- Cybersecurity by design specifications for hardware, software and infrastructure deployments; unit and integration testing compulsory;
- Logical decentralisation of equipment and processes to prevent single point of failure;
- Incorporation of techniques like multi-factor authentication, zero-knowledge proofs, differential privacy, advanced biometrics and/or hardware security modules to increase friction for tampering with systems;
- Edge intelligence on air-gapped equipment to prevent remote tampering;
- Secure data storage and deletion; compliant with data privacy regulations.

Implications for curriculum design: the need for cybersecurity professionals in the Advanced Manufacturing context will increase greatly. Employees involved in cybersecurity must be trained to work closely with other IT and Information Security colleagues. Workers must be well-versed in networking paradigms, ethical hacking, and able to work effectively in a complex real-time environment with multiple devices, software and running processes.

Product-Service Systems

Product-Service Systems (PSSs) can be defined as tangible products and intangible services designed and combined so that they jointly fulfil specific customer needs[586]. Products with associated services not only command a premium and build loyalty, they are also capable of gathering usage data and delivering value-added enhancements to services iteratively. However it should be noted that delivering a PSS is a strategic move and is intrinsically tied to the (digital) business model of the company. As such, PSS is a promising direction for advanced manufacturing in the context of supporting digital business models, whose data insights feed back into the design of new products in an end-to-end loop. The following are the technological applications that come to bear[587,588]:

- Close integration of hardware and software features and capabilities;
- Usage data capture and storage; compliance with data privacy regulations;
- Data analytics to identify patterns and personalise services;
- Cybersecurity to maintain integrity and prevent tampering;
- Cloud computing integration for deploying apps and updates;
- Digital customer feedback mechanisms;
- Digital rights management for “timed” or “pay-per-use” actions;
- Digital payments for secure and frictionless service purchases;
- Incorporating new hardware technologies like hardware security modules (HSMs), biometrics, neuromorphic chips etc. to provide user-centric personalised features.

586 Tukker, A. (2004) “Eight Types of Product-Service System: Eight Ways to Sustainability? Business Strategy and the Environment, 13

587 PwC analysis incorporating multiple expert sources

588 Tukker, A. (2004). Eight Types of Product-Service System: Eight Ways to Sustainability? Business Strategy and the Environment, 13

Implications for curriculum design: to deliver a successful PSS, both hardware and software need to work seamlessly from the customer point of view. This means employees from both the hardware product design and software engineering need to be aligned and working together on a unified product roadmap. Moreover, once the product is manufactured and in the hands of consumers, a significant portion of the workforce will be involved in supporting the software stack and data flows.

Sustainability & Circular Economy

According to the IPCC Special Report from October 2018, human-caused carbon emissions are accelerating climate change with potentially severe impacts if this global emissions are not halved by 2030 with the target of reaching and sustaining net-zero emissions by 2050[589]. In this context, reducing emissions from industrial activity such as manufacturing and the associated value chain would be a critical necessity. Deep application of sustainability within the industrial context would require significant reinvention and optimisation of products, services and processes. Technology can help in this regard[590,591]:

- High density of IoT sensors and actuators combined with real-time synthesis of data streams to create “digital twins” – optimising for efficiency and emissions reduction;
- Artificial intelligence enabled energy and material usage optimisation;
- On-demand decentralised manufacturing (enabled by 3D printing for example) to minimise waste and distance travelled;
- Electric mobility to reduce net emissions from transportation – including trucks, ships, trains;
- Powering business and factories with exclusively renewable energy;
- Designing for and extending product lifecycles with better service, support, maintenance and repair;
- Enabling circular economy by designing products for easy dismantling and reuse;
- Designing energy-efficient products and services;
- Technologies for recovering valuable materials and components from existing products;
- Blockchains for tamper-proof recording of provenance, transit, transaction and recovery of products;
- Enabling circular economy by creating a “reverse-logistics” supply chain – where products in the hands of consumers eventually find their way back to the manufacturer to be reused;

589 Intergovernmental Panel on Climate Change. (2018) “Global Warming of 1.5 °C an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change”. Retrieved October 15, 2018

590 PwC analysis incorporating multiple expert sources

591 Najouk, N., Le Fleming, H., & Srivatsav, N. (2018) “Digital Technology and Sustainability: Positive Mutual Reinforcement”. Retrieved October 15, 2018

- Designing products and services for the sharing economy, supported by digital demand-response platforms;
- Digitising products and services wherever possible – for example streaming media is preferable to manufacturing DVDs and DVD players.

Implications for curriculum design: the urgent and large-scale need to shift to sustainable production implies that industries, including manufacturing, must consider holistic and fundamental shifts in the manufacturing environment. Fortunately, this coincides with the equally necessary shift to Industry 4.0, and as it happens, digital technologies can be a key enabler for sustainability[592]. Workers and management need to be understand and be motivated to act on sustainability – not only from an economic standpoint, but also a moral one.

Moreover, designing for sustainability is an opportunity area to diversify products and services. Lean manufacturing is focussed on minimising waste in the production cycle perspective; at the same time, the circular economy approach is also focussed on minimising waste from the product lifecycle perspective. Thus there is a lot of synergy and potential to be tapped. Workers need to be trained in (and rewarded for) extending the use of software like process simulations, AI optimisation, blockchain etc. to achieve both business and environmental goals.

592 van den Beukel, J.-W. (2017) "Industry 4.0 as an enabler of the Circular Economy: preventing the waste of value and permitting the recovery of value from waste". Retrieved October 15, 2018

ANNEX D: GOOD PRACTICE CURRICULUM DESCRIPTIONS

D.1. Manufacturing Engineering Tripos, University of Cambridge (UK)

TABLE D-1: Manufacturing Engineering Tripos, University of Cambridge (UK)

Nr	Item	Description
1.	***General characteristics***	**Title:** Manufacturing Engineering Tripos (MET)[593] **Education/ training provider:** University of Cambridge **Country:** United Kingdom **International orientation:** Partly. The course has an international flavour, with many students involved in activities with other European students of manufacturing through the ESTIEM organisation. **Duration:** 2 years (of a 4 years BSc.) **Target group:** Undergraduates on the Cambridge Engineering Degree.
2.	***Objectives and essence***	• **Key objectives:** The course prepares students to be leaders of business and technology firms. It provides a thorough grounding in management and manufacturing technologies, together with an understanding of the full range of industrial activities. • **Expected learning outcomes:** Develop understanding of how the engineering, financial, organisational and human aspects of firms work. This spans all aspects of the firm, from the design of new products, materials and production technologies, industrial engineering, through to marketing, business strategy and operations management. • **Brief description:** The course is an option for the final two years of Cambridge Engineering Degree, combining subject modules and integrating activities such as industrial visits and projects, automation lab and business skills development. • **Costs:** Tuition fee for home fee status students starting their first undergraduate course in 2019 is GBP 9,250 per year[594]. Tuition fee for home fee status students starting their second undergraduate course in 2019 is GBP 10,368 in addition to college fees ranging between GBP 6,850 and 12,700 per year[595]. Tuition fee for overseas students commencing in October 2019 is GBP 30,678 per year[596]. In addition students are required to cover the expenses of a digital tablet. The tablet costs between GBP 100-300.
3.	***Relevance to addressing the new skill needs***	How the programme addresses: • **Multidisciplinary orientation**: The course combines manufacturing technology, manufacturing engineering and business management, through projects and 10 and 6 modules undertaking the first and second year, respectively. • **Dual/alternate education**: During the first year of the course students undertake 6 industrial visits. During the final year of the course students spend periods in industry doing real industrial projects. • **Embedding non-technical courses**: A distinctive feature of the course is the Business Skills Development Programme designed to develop some of the personal skills critical for success in industry and related employment. • **Problem-based/challenge driven learning**: The course couples theory with the repeated experience of putting theory into practice via a series of projects. Students undertake both a major design project in their first year and real industrial projects during their second year of the course. • **Student-led learning**: Based on the available information, students

593 The course webpage is used as source unless otherwise stated. https://www.ifm.eng.cam.ac.uk/uploads/Education/MET/MET_recruitment_Feb_2018_information_Final.pdf
594 https://www.undergraduate.study.cam.ac.uk/fees-and-finance/tuition-fees
595 https://www.undergraduate.study.cam.ac.uk/why-cambridge/support/mature-students/second-undergraduate-degrees
596 https://www.undergraduate.study.cam.ac.uk/international-students/fees

Nr	Item	Description
		appear to have a limited role in defining their curriculum. Exception is in the selection of industrial projects. There is no available information on students' opportunity to influence the curricula in specific subjects.
4.	***Curriculum framework***	• **Broad Fields[597]:** Curriculum is built around five main topics: How to design the product, how to make the components, how to organize the factory, how to manage the business and the business context. Relationships between subjects are further emphasised through integrating activities such as projects, automation lab and industrial visits.
5.	***Delivery mechanisms***	• **In person delivery (classical delivery):** Teaching is done through use of lectures, on-sites visits, laboratory work and project participation, hinging on student presence.
6.	***Impact***	• **Nr of graduates**: 41 graduates 2018[598]

D.2. MSc. Industrial Systems, Manufacturing and Management (ISMM), University of Cambridge (UK)

TABLE D-2: MSc. Industrial Systems, Manufacturing and Management (ISMM), University of Cambridge (UK)

Nr	Item	Description
1.	***General characteristics***	**Title:** MSc. Industrial Systems, Manufacturing and Management (ISMM)[599] **Education/training provider:** University of Cambridge **Country:** United Kingdom **International orientation**: No. Based on the available information the course does not appear to be internationally oriented. **Duration:** 1 year **Target group:** Potential graduate students with complete BSc. in relevant subjects.
2.	***Objectives and essence***	• **Key objectives:** The course is designed to equip numerate graduates, primarily from STEM backgrounds, with the skills, personal development and industrial experience to be immediately effective in their early careers in industry. • **Expected learning outcomes:** The course consists of modules which aim to provide detailed theoretical knowledge relating to all aspects of modern manufacturing. Modules seek to develop insight into the complexity of industrial systems, building on an overview of core 'manufacturing processes', through to understanding the operation of global supply chains and the role of manufacturing firms in the wider economy. • **Brief description:** The learning ethos that underpins the course is best described as 'learn it', 'see it', 'do it'. The programme is structured around taught modules, company visits and in-company projects solving live business or technical problems. • **Costs[600]:** Tuition for home students in 2018/19 is GBP 28,913. Tuition for EU students in 2018/19 is GBP 29,263. Tuition for overseas students in 2018/19 is GBP 49,072.

597 The curriculum is organised to cut across subject lines and to emphasize relationships between subjects. It usually if organised into a 3 to 5 fields. For example, fields for technical career learning, professional and personal growth, supporting sciences, etc. Based on the methodology of ABC Curriculum Resources, available at: http://gotootheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles

598 http://www.information-hub.admin.cam.ac.uk/university-profile/ug-examination-results/results-course-dashboard data collected Oct. 23rd 2018

599 The course webpage is source of information unless otherwise stated. https://www.ifm.eng.cam.ac.uk/education/ismm/course-overview/

600 https://www.graduate.study.cam.ac.uk/courses/directory/egegmpimm/finance

Nr	Item	Description
3.	***Relevance to addressing the new skill needs***	How the programme addresses: • **Multidisciplinary orientation**: The course combines manufacturing and business management through project, research dissertation and modules. Business subjects include New Business Development, Innovation and IP and International Business. • **Dual/alternate education**: The students obtain industry experience during the course through industry projects. • **Embedding non-technical courses**: Through the course students learn professional skills such as data gathering and analysis, presentation skills, report writing and balancing theory with practice, and obtain personal attributes such as problem solving, teamwork, a 'can do' attitude and leadership skills. • **Problem-based/challenge driven learning**: The students undertake 4 industrial projects throughout the course. Each project deals with a live issue relevant to the company. • **Student-led learning**: Students have a limited role in defining their curriculum. Exception is in the selection of industrial projects and research dissertation project. There is no available information on students' opportunity to influence the curricula in specific subjects.
4.	***Curriculum framework***	• **Subject or Discipline-Centred[601]:** The curriculum is centred around a set of subjects. Projects, industrial visits and research allows for seeing relationships between the subjects.
5.	***Delivery mechanisms***	• **In person delivery (classical delivery):** Teaching is done through use of lectures, on-sites visits and project participation, hinging on student presence. Large use of teamwork.
6.	***Impact***	• **Nr of graduates:** 41 students 2017/18[602]

D.3. BSc. Industrial Design Engineering, Delft University of Technology (Netherlands)

TABLE E-D: BSc. Industrial Design Engineering, Delft University of Technology (Netherlands)

Nr	Item	Description
1.	***General characteristics***	**Title:** BSc. Industrial Design Engineering[603] **Education/training provider:** Delft University of Technology **Country:** The Netherlands **International orientation:** Partly. The course is taught in English and student have opportunity to undertake parts of the study abroad. **Duration:** 3 years **Target group:** Potential undergraduate students
2.	***Objectives and essence***	• **Key objectives:** Students are challenged to devise new solutions. They are encouraged to be curious, tolerant, collaborative, determined, inspiring and creative, so that they will soon be prepared to design our future. • **Expected learning outcomes:** This curriculum emphasises the design of products and systems. Students receive design assignments and integrate the knowledge and skills taught in the multi-disciplinary modules. They also

601 The curriculum is organised around separate, specific subjects or disciplines. Based on the methodology of ABC Curriculum Resources, available at: http://gototheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles

602 https://www.prao.admin.cam.ac.uk/data-analysis-planning/student-numbers/snapshot-courseschooldepartment

603 The course webpage is used as source unless otherwise stated. https://www.tudelft.nl/en/ide/education/bsc-industrial-design-engineering/

Nr	Item	Description
		learn to visualise concepts, to give presentations and to perform technical documentation. In addition, students discover how products tare technically well-made, what the cultural meaning of products is, and the roles that they play in people's lives. Other important curriculum components include research to develop new ideas and to the ability to view products from a commercial perspective. • **Brief description:** During the first two years, students will take modules in product development (PD), along with multi-disciplinary modules. The PD courses form the common thread of the programme. In the third and final year, students will take a minor and two elective modules, in addition to working full-time on the final project for 10 weeks. Throughout the programme, theory is alternated with practical exercises and projects • **Costs[604]:** Tuition fee for EU/EFTA students in 2019/20 is EUR 2,083. Tuition fee for non-EU students in 2019/20 is proposed to be EUR 14,500.
3.	***Relevance to addressing the new skill needs***	How the programme addresses: • **Multidisciplinary orientation**: Design exercises are the backbone of the degree programme. In these design exercises, you will apply knowledge and skills from a variety of disciplines related to IDE: Engineering, Ergonomics, Design, Marketing and consumer behaviour and Sustainability. • **Dual/alternate education**: Students can choose to complete an internship, in the Netherlands or abroad, instead of doing a minor in their third year. • **Embedding non-technical courses**: Based on the available information, the course does not appear to embed non-technical courses. • **Problem-based/challenge driven learning**: Based on the available information, the course does not appear to use problem-based or challenge driven learning. • **Student-led learning**: In the course's third year, students have large freedom to choose subject, minor and topic for the final bachelor project. There is no available information on students' opportunity to influence the curricula in specific subjects.
4.	***Curriculum framework***	• **Spiral[605]:** Production development (PD) subjects form the basis of the course and is revisited several times during the programme. The PD courses are supplemented with additional subjects.
5.	***Delivery mechanisms***	• **Blended delivery:** Teaching is mostly done through use of lectures and project participation, hinging on student presence. However, there has also been launched online training sessions.
6.	***Impact***	• No information was found.

604 https://www.tudelft.nl/en/education/practical-matters/tuition-fee-finances/

605 The curriculum is organised around key concepts/skills that are introduced and revisited for deeper understanding as the learner moves through the program of study. Source: Ibid.

D.4. MSc. Mechanical Engineering, Delft University of Technology (Netherlands)

TABLE D-4: MSc. Mechanical Engineering, Delft University of Technology (Netherlands)

Nr	Item	Description
1.	***General characteristics***	**Title:** MSc. Mechanical Engineering[606] **Education/training provider:** Delft University of Technology **Country:** The Netherlands **International orientation:** Yes. The course is open for international students and taught in English. International experience encouraged. **Duration:** 2 years **Target group:** Potential graduate students with completed BSc. in relevant subjects.
2.	***Objectives and essence***	• **Key objectives:** The goal of the MSc Programme in Mechanical Engineering is to give students a broad, in-depth understanding of all mechanical engineering disciplines. The programme trains engineers to handle the entire process of innovative thinking, design, manufacturing and operation. • **Expected learning outcomes:** Depends on the chosen track. • **Brief description:** In the MSc Programme in Mechanical Engineering, students begin straight away in one of the five tracks. Each track teaches you the basics of mechanical engineering, whether in the medical sector or on large industrial plants. • **Costs[607]:** Tuition fee for EU/EFTA students in 2019/20 is EUR 2,083. Tuition fee for non-EU students is 2019/20 is proposed to be EUR 18,750.
3.	***Relevance to addressing the new skill needs***	How the programme addresses: • **Multidisciplinary orientation**: Based on the available information, the course does not appear to have a multidisciplinary orientation. • **Dual/alternate education**: Some of the offered tracks allow for industrial traineeships • **Embedding non-technical courses**: Based on the available information, the course does not appear to embed non-technical courses. • **Problem-based/challenge driven learning**: Based on the available information, the course does not appear to use problem-based or challenge driven learning. • **Student-led learning**: Students have a large flexibility in choosing subjects and thus defining the content of their masters. There is no available information on students' opportunity to influence the curricula in specific subjects.
4.	***Curriculum framework***	• **Subject or Discipline-Centred[608]:** The course is to a large extent discipline-centred, given the five available tracks.
5.	***Delivery mechanisms***	• **In person delivery (classical delivery)**: Teaching is done through use of lectures and project participation, hinging on student presence.
6.	***Impact***	• No information was found.

606 The course webpage is used as source unless otherwise stated. https://www.tudelft.nl/en/education/programmes/masters/mechanical-engineering/msc-mechanical-engineering/
607 https://www.tudelft.nl/en/education/practical-matters/tuition-fee-finances/
608 The curriculum is organised around separate, specific subjects or disciplines. Based on the methodology of ABC Curriculum Resources, available at: http://gototheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles

D.5. BSc. Industrial Production Engineering, Politecnico di Milano (Italy)

TABLE D-5: BSc. Industrial Production Engineering, Politecnico di Milano (Italy)

Nr	Item	Description
1.	***General characteristics***	**Title:** BSc. Industrial Production Engineering[609] **Education/training provider:** Politecnico di Milano **Country:** Italy **International orientation:** No. Teaching in Italian. **Duration:** 3 years **Target group:** Potential undergraduate students
2.	***Objectives and essence***	• **Key objectives:** The programme has the objective of preparing a new, for the Italian context, engineering figure, the industrial engineer, present for many years now on the international scene: a professional who conceives industry as a system to be designed, organised and managed. He/she must therefore have the necessary skills to dominate such a system from its initial design phase through to its management, in the meantime optimising its processes, technological cycles, systems, plant, logistics, and so on. • **Expected learning outcomes:** The programme aims to provide an appropriate background, in scientific subjects including mathematics, calculus and physics, and a sound knowledge of the basics of mechanical engineering subjects and of management engineering. The specific subjects for this programme concern the design and management of industrial plants and all mechanical production technologies. Three different learning objectives have been identified: 1) understand the main fundamentals of engineering and their implementation in the different production technologies and processes; 2) learn about the context variables, functions and fundamental processes in mechanical and industrial processes; 3) design engineer and manage production models and systems through the lens of a scientific rigorous approach, in a business setting. • **Brief description:** The Industrial Production Engineering Bachelor Degree lasts three years and is worth 180 ECTS credits. The first and second years are common for all students. The third year conversely differentiates according to the choice of programme. Specialisation in the third year are preparing for masters in Mechanical Engineering, Masters in Management Engineering and the job market. • **Costs[610]:** The basic all-inclusive contribution is equal to EUR 3,726. This amount, however, must be fully paid only by a limited number of students; in most cases, there is the possibility of financial aid that allows to reduce the contribution of a significant amount.
3.	***Relevance to addressing the new skill needs***	How the programme addresses: • **Multidisciplinary orientation**: The course mainly consists of subjects within manufacturing and industrial production, but does also include subjects on computer science and economics and business administration[611]. One of the offered specialisations further elaborates in the management perspective of manufacturing.

609 The course webpages are used as sources unless otherwise stated. http://www.polinternational.polimi.it/educational-offer/laurea-equivalent-to-bachelor-of-science-programmes/industrial-production-engineering/ and https://www4.ceda.polimi.it/manifesti/manifesti/controller/extra/RegolamentoPublic.do?jaf_currentWFID=main&EVN_DEFAULT=evento&aa=2018&k_corso_la=367&lang=EN

610 https://www.polimi.it/en/current-students/tuition-fees-scholarships-and-financial-aid/student-contribution/

611 https://www4.ceda.polimi.it/manifesti/manifesti/controller/ManifestoPublic.do?&aa=2018&k_cf=225&k_corso_la=367&ac_ins=0&k_indir=PGG&lang=EN&tipoCorso=ALL_TIPO_CORSO&caricaOffertaInvisibile=false&semestre=ALL_SEMESTRI

Nr	Item	Description
		• **Dual/alternate education**: In one of the three possible specialisations for the third year, students undertake two traineeships[612]. • **Embedding non-technical courses**: Based on the available information, the course does not appear to embed non-technical courses. • **Problem-based/challenge driven learning**: Based on the available information, the course does not appear to use problem-based or challenge driven learning. • **Student-led learning**: Students can choose specialisation for their third year. Otherwise, little degree of student-led learning. There is no available information on students' opportunity to influence the curricula in specific subjects.
4.	***Curriculum framework***	• **Subject or Discipline-Centred[613]:** The course is centred on a set of subjects, which combined deliver the course objective.
5.	***Delivery mechanisms***	• **In person delivery (classical delivery):** Teaching is done through use of lectures and project work, hinging on student presence.
6.	***Impact***	• No information was found.

D.6. Global Master in Industrial Management, Politecnico di Milano (Italy)

TABLE D-6: Global Master in Industrial Management, Politecnico di Milano (Italy)

Nr	Item	Description
1.	***General characteristics***	**Title:** Global Master in Industrial Management (GMIM)[614] **Name of education/training provider:** Politecnico di Milano **Country:** Italy **International orientation:** Yes. The programme is taught entirely in English and delivered in a highly internationalised environment with the possibility to spend the 4 semesters of the course in up to 4 different countries across Europe and Asia. **Duration:** 18 to 22 months **Target group:** Potential graduate students with completed BSc. in relevant subjects.
2.	***Objectives and essence***	• **Key objectives:** The GMIM programme aims to provide students with the competencies and skills necessary to develop a successful career in internationally orientated manufacturing and service industries. The programme seeks to bridge the gap between university and industry, by teaching the relevant knowledge and skills essential for effective managerial practices, especially the skills and knowledge not traditionally taught in technical or scientific university programmes. • **Expected learning outcomes:** Emphasis on relevant managerial topics that are highly beneficial for graduates of technical university programmes, such as operations and supply chain management. The study of concentration streams, as chosen by the student according to preference or region of interest, which allow the students

612 https://www4.ceda.polimi.it/manifesti/manifesti/controller/ManifestoPublic.do?&aa=2018&k_cf=225&k_corso_la=367&ac_ins=0&k_indir=PGG&lang=EN&tipoCorso=ALL_TIPO_CORSO&caricaOffertaInvisibile=false&semestre=ALL_SEMESTRI

613 The curriculum is organised around separate, specific subjects or disciplines. Based on the methodology of ABC Curriculum Resources, available at: http://gototheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles

614 The course webpage is used as source unless otherwise stated. http://www.mip.polimi.it/en/academics/people-and-careers/masters/imim-international-master-in-industrial/

Nr	Item	Description
		to focus their studies on a particular area of managerial theory. • **Brief description:** Students will spend each of the three first semesters at one of the partner institutions: starting in Glasgow, UK, and subsequently continuing with the second semester in Milan, Italy and the last one in either Munich (Germany), Beijing (China) or Toulouse (France). The final semester is set of to the Master thesis which can be done anywhere in the world. • **Costs:** Tuition fee for EU students is EUR 17,500. Tuition fee for non-EU students is EUR 19,500.
3.	***Relevance to addressing the new skill needs***	How the programme addresses: • **Multidisciplinary orientation**: The course places great emphasis on fostering an integrative teaching approach aimed at developing the ability of students to tackle issues in an interdisciplinary manner, while additionally providing an overview of general management concepts, such as marketing and accounting, in an industrial context. • **Dual/alternate education**: The programme offers, through close collaboration with associated industrial and service companies, the chance for students to combine practical and relevant knowledge and skills with invaluable industry experience. Students can choose between undertaking a company or university based Master thesis. • **Embedding non-technical courses**: Personal Development workshops is offered to help students develop the soft skills necessary to be competitive in today's job market. • **Problem-based/challenge driven learning**: Based on the available information, the course does not appear to use problem-based or challenge driven learning. • **Student-led learning**: Students can choose location and topic for their third term. There is no available information on students' opportunity to influence the curricula in specific subjects.
4.	***Curriculum framework***	• **Broad Fields[615]:** The course is largely structured around the four rotations to different locations in the world, each rotation covering a particular field.
5.	***Delivery mechanisms***	• **In person delivery (classical delivery):** Teaching is done through use of lectures and projects, hinging on student presence. While writing their Master thesis, students can be located anywhere in the world.
6.	***Impact***	• **% of graduates getting a job right after graduation:** 40% employed by graduation. 88% employed within 1 year of graduation.

615 The curriculum is organised to cut across subject lines and to emphasize relationships between subjects. It usually if organised into a 3 to 5 fields. For example, fields for technical career learning, professional and personal growth, supporting sciences, etc. Based on the methodology of ABC Curriculum Resources, available at: http://gototheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles

D.7. BSc Materials and Process Engineering Specialisation, RWTH Aachen University (Germany)

TABLE D-7: BSc. Materials and Process Engineering Specialisation, RWTH Aachen University (Germany)

Nr	Item	Description
1.	***General characteristics***	**Title:** BSc. Materials and Process Engineering Specialization[616] **Education/training provider:** RWTH Aachen University **Country:** Germany **International orientation:** Partly. The course is taught in German, but students have the opportunity to study one or two semester at another university. **Duration:** 6 semesters (3 years) **Target group:** Potential undergraduate students
2.	***Objectives and essence***	• **Key objectives:** Educate material engineers that can bridge the gap between engineers and business experts, and that can help innovate through newly developed materials. • **Expected learning outcomes:** In order to be able to master the split between various business objectives, students acquire skills in both a technical discipline and business administration. • **Brief description:** In contrast to comparable courses of study the course of study at RWTH Aachen offers a clear engineering focus. This focus allows budding engineers to build technical application skills. Starting in the fourth semester students can select four elective modules from five engineering focuses in order to create their own individual profile: Materials engineering (glass, ceramics, metals), Materials processing (casting or moulding), Metallurgy and recycling (non-ferrous metals or iron and steel), Transport phenomena and Plastics engineering. • **Costs:** University fee of EUR 42[617].
3.	***Relevance to addressing the new skill needs***	How the programme addresses: • **Multidisciplinary orientation**: Business management and economics subjects such as Investment and Financing and Internal Accounting and Bookkeeping is included in the course. • **Dual/alternate education**: Before enrolling students must complete a technical pre-internship lasting four weeks. During their sixth semester students complete an industry internship in engineering or business sector. • **Embedding non-technical courses**: Based on the available information, non-technical courses does not appear to be embedded in the course. • **Problem-based/challenge driven learning**: Based on the available information, the course does not appear to use problem-based or challenge driven learning. • **Student-led learning**: Based on the available information, it appears that the course does not offer student-led learning. There is no available information on students' opportunity to influence the curricula in specific subjects.
4.	***Curriculum framework***	• **Subject or Discipline-Centered[618]:** This subject offers a broad combination of basic natural science subjects and engineering fundamentals. Students do not specialise in order to take advantage of

616 The course webpage is used as source unless otherwise stated. http://www.rwth-aachen.de/cms/root/Studium/Vor-dem-Studium/Studiengaenge/Liste-Aktuelle-Studiengaenge/Studiengangbeschreibung/~bpwa/Wirtschaftsingenieurwesen-B-Sc-Fachric/?lidx=1

617 http://www.rwth-aachen.de/go/id/bqmo/lidx/1

618 The curriculum is organised around separate, specific subjects or disciplines. Based on the methodology of ABC Curriculum Resources, available at: http://gototheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles

Nr	Item	Description
		the comprehensive and broad fundamental training.
5.	***Delivery mechanisms***	• **In person delivery (classical delivery):** Teaching is done through use of lectures, hinging on student presence.
6.	***Impact***	• No information was found.

D.8. MSc. Materials and Process Engineering Specialisation, RWTH Aachen University (Germany)

TABLE D-8: MSc. Materials and Process Engineering Specialisation, RWTH Aachen University (Germany)

Nr	Item	Description
1.	***General characteristics***	**Title:** MSc. Materials and Process Engineering Specialization[619] **Education/training provider:** RWTH Aachen University **Country:** Germany **International orientation:** No. The course is taught in German. **Duration:** 4 semesters (2 years) **Target group:** Potential graduate students with completed BSc. in relevant subjects.
2.	***Objectives and essence***	• **Key objectives:** Graduates from this programme are optimally education for the cross-section between technical and business processes. Because this course of study is also research-oriented, graduates can complete doctoral studies on either a technical or business topic. • **Expected learning outcomes:** The study of industrial engineering equally covers topics from economics and engineering courses of study. By selecting the specialisation in materials and process engineering, students spend the engineering part of their studies on materials development, manufacture, and processing. Aside from founded technical knowledge, the course of study also teaches students comprehensive business know how. • **Brief description:** A particular characteristic of this course of study is that students specialise in a material or material group and/or a process during the technical portion. As part of this specialisation, students attend courses throughout their Master's studies, so that they can exhibit their vast knowledge about their selected specialisation at the end of their studies. • **Costs:** University fee of EUR 42[620].
3.	***Relevance to addressing the new skill needs***	How the programme addresses: • **Multidisciplinary orientation**: The course combines engineering and business courses. • **Dual/alternate education**: Courses contain internship, in which students independent prepare and implement trials, and complete a report of the trial afterwards. Each semester, students have the possibility to visit production or research sites in materials engineering during one to five-day excursions. • **Embedding non-technical courses**: Based on the available information, non-technical courses does not appear to be embedded in

619 The course webpage is used as source unless otherwise stated. http://www.rwth-aachen.de/cms/root/Studium/Vor-dem-Studium/Studiengaenge/Liste-Aktuelle-Studiengaenge/Studiengangbeschreibung/~bmoa/Wirtschaftsingenieurwesen-M-Sc-Fachric/?lidx=1

620 http://www.rwth-aachen.de/go/id/bqmo/lidx/1

Nr	Item	Description
		the course. • **Problem-based/challenge driven learning**: Based on the available information, the course does not appear to use problem-based or challenge driven learning. • **Student-led learning**: Students choose specialisation subjects for their first three semesters, s well as topic for the master thesis. There is no available information on students' opportunity to influence the curricula in specific subjects.
4.	***Curriculum framework***	• **Broad Fields[621]:** The course consist of modules, meaning that curriculum content is bundled together into different units or modules.
5.	***Delivery mechanisms***	• **In person delivery (classical delivery):** Teaching is done through use of lectures and project work, hinging on student presence.
6.	***Impact***	• No information was found.

D.9. BSc. Mechanical Engineering, KTH Royal Institute of Technology (Sweden)

TABLE D-9: BSc. Mechanical Engineering, KTH Royal Institute of Technology (Sweden)

Nr	Item	Description
1.	***General characteristics***	**Title:** BSc. Mechanical Engineering (CMAST)[622] **Education/training provider:** KTH Royal Institute of Technology **Country:** Sweden **International orientation:** Partly. The course is mainly taught in Swedish. Students can choose an international track for their second and third years, and can choose to spend one semester abroad. **Duration**: 3 years **Target group:** Potential undergraduate students
2.	***Objectives and essence***	• **Key objectives:** Students should demonstrate broad knowledge within the chosen technical field, including knowledge in mathematics and natural science, and substantial specialised knowledge within certain parts of the field. • **Expected learning outcomes:** The course provides students with a broad scientific foundation that enables them to work within a number of technical fields with product development, production and manufacturing technology and energy issues. This may include material selection, energy sources, production methods of the assessment of economic and environmental impact, etc. • **Brief description:** The programme consists of compulsory, conditionally elective, recommended and optional courses. The compulsory and conditionally elective courses are defined for each year in course lists. The programme is designed so that the student, after three years, has the opportunity to obtain a technical Degree of Bachelor. • **Costs[623]:** There is no tuition fees for EU/EEA/Swiss students. Tuition fee for non-EU/EEA/Swiss students is SEK 122,000 (approx. EUR 11,700) per year.

621 The curriculum is organised to cut across subject lines and to emphasize relationships between subjects. It usually if organised into a 3 to 5 fields. For example, fields for technical career learning, professional and personal growth, supporting sciences, etc. Based on the methodology of ABC Curriculum Resources, available at: http://gototheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles
622 The English and Swedish course webpages are used as sources unless otherwise stated. https://www.kth.se/student/kurser/program/CMAST/20172/genomforande?l=en https://www.kth.se/utbildning/civilingenjor/maskinteknik
623 https://www.kth.se/en/studies/bachelor/fees-1.646274

Nr	Item	Description
3.	***Relevance to addressing the new skill needs***	How the programme addresses: • **Multidisciplinary orientation**: Based on the available information, the course does not appear to be multidisciplinary oriented. • **Dual/alternate education**: Based on the available information, industry experience does not appear to be an integrated part of the curriculum. • **Embedding non-technical courses**: The teaching and use of professional skills and abilities of great importance to a certified engineer, for example, corporate and societal aspects, communication and sustainable development, are integrated into the courses. • **Problem-based/challenge driven learning**: Based on the available information, the course does not appear to use problem-based or challenge driven learning. • **Student-led learning**: Students can individually select several subjects in their second and third years to define their bachelor's degree. There is no available information on students' opportunity to influence the curricula in specific subjects.
4.	***Curriculum framework***	• **Broad Fields[624]:** To create a unified whole, the programme emphasises cooperation between different subjects, both within a specific year and between years. This is achieved through courses being coordinated on the schedule, via joint degree projects and written assignments.
5.	***Delivery mechanisms***	• **In person delivery (classical delivery):** Teaching is done through use of lectures and project work, hinging on student presence.
6.	***Impact***	• No information was found.

D.10. MSc. Production Engineering and Management, KTH Royal Institute of Technology (Sweden)

TABLE D-10: MSc. Production Engineering and Management, KTH Royal Institute of Technology (Sweden)

Nr	Item	Description
1.	***General characteristics***	**Title:** MSc. Production Engineering and Management[625] **Education/training provider:** KTH Royal Institute of Technology **Country:** Sweden **International orientation:** Partly. The course is taught in English, and students have the opportunity to do part of their studies abroad. **Duration:** 2 years **Target group:** Potential graduate students with completed BSc. in relevant subjects.
2.	***Objectives and essence***	• **Key objectives:** The programme provides a strong foundation to become a professional with knowledge in both engineering and management aspects of production and their interaction. The engineering side includes operation and integration of manufacturing technology, automation, maintenance and quality aspects, production development tools, and methods as well as software. The management side covers systematic decision-making, operations strategy, planning, control and management of resources that are essential for achieving a sustainable production

624 The curriculum is organised to cut across subject lines and to emphasize relationships between subjects. It usually if organised into a 3 to 5 fields. For example, fields for technical career learning, professional and personal growth, supporting sciences, etc. Based on the methodology of ABC Curriculum Resources, available at: http://gototheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles

625 The course webpage is used as source unless otherwise stated. https://www.kth.se/en/studies/master/production-engineering-management/course-overview-1.8648

Nr	Item	Description
		environment. • **Expected learning outcomes:** After graduating from the programme students will have: Basic understanding of various dimensions and functions of the broad field of production. Analytical skills needed to tackle the ever-changing problems and situations of modern competitive production. Conceptual and reasoning skills with appropriate decision support methods and tools used in production management. Communication and presentation skills necessary for leadership positions. Understanding of how environmental and cultural differences effect the production process. Understanding of the need and requirements for sustainable and energy efficient production processes. • **Brief description:** In order to create a strong foundation students follow a certain number of mandatory courses. On top of that the students have the possibility to deepen their knowledge in production engineering, development and management, as well as information management in industry. The programme emphasises on both theoretical knowledge and applied skills which are covered through project course, individual and group assignments/projects, individual and group laboratory works, industrial visits. Furthermore, to maintain relevance to the state-of-the-art industrial developments and research, leading researchers and industrial professionals are invited to share their knowledge with our students. The educational activities and the structures promotes self-learning, trains students how to communicate effectively with different stakeholders, and generates a study environment that provides equal learning opportunity. • **Costs:** There is no tuition fee for EU/EEA/Swiss students. Tuition fee for non-EU/EEA/Swiss students is SEK 310,000 (approx. EUR 29,800) for the full programme.
3.	***Relevance to addressing the new skill needs***	How the programme addresses: • **Multidisciplinary orientation**: The course combines subjects of engineering and business management. • **Dual/alternate education**: Based on the available information, industry experience does not appear to be an integrated part of the curriculum. • **Embedding non-technical courses:** Based on the available information, the course does not appear to embed non-technical courses. • **Problem-based/challenge driven learning:** Based on the available information, the course does not appear to use problem-based or challenge driven learning. • **Student-led learning:** Based on the available information, students appear to have a limited role in defining their curriculum. There is no available information on students' opportunity to influence the curricula in specific subjects.
4.	***Curriculum framework***	• **Broad Fields[626]:** The course has four recommended profiles, with specific subjects making the foundations of these profiles.
5.	***Delivery mechanisms***	• **In person delivery (classical delivery):** Teaching is done through use of lectures and project assignment, hinging on student presence.
6.	***Impact***	• No information was found.

626 The curriculum is organised to cut across subject lines and to emphasize relationships between subjects. It usually if organised into a 3 to 5 fields. For example, fields for technical career learning, professional and personal growth, supporting sciences, etc. Based on the methodology of ABC Curriculum Resources, available at: http://gototheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles

ANNEX E: AMT-RELATED LABOUR SUPPLY FOR EACH AMT-RELATED OCCUPATION PER MEMBER STATE

The Table below contains the estimated excess AMT-related labour supply for each AMT-related occupation in each Member State. In addition, one can find the estimated required labour supply growth for each AMT-related occupation over the period 2017 to 2026 in order to have a balanced AMT-related labour market in 2026, given the assumptions of this analysis.

The analysis suggests that all European economies, except Czech Republic, are estimated to have excess AMT-related labour supply for all AMT-related occupations in 2026. This indicated that the estimated AMT-related labour supply growth is larger than the growth necessary to have a balanced market in 2026, and/or that that there will remain market frictions not related to occupational level on the AMT-related labour market. These frictions can, for instance, refer to lack of skills within an occupation and geographical unbalance within countries.

TABLE E-1: AMT labour market on occupational level for European countries

European Union (current composition)	Excess AMT labour supply (thousand)		Required AMT labour supply growth (thousand)
	2017	2026	2026 demand - 2017 supply
Managers	134,6	144,6	19,5
Professionals	236,8	275,6	360,6
Technicians and associate professionals	353,8	376,7	-0,8
Craft and related trades workers	706,0	621,8	-2001,6
Plant and machine operators and assemblers	464,7	456,4	-592,4

Austria	Excess AMT labour supply (thousand)		Required AMT labour supply growth (thousand)
	2017	2026	2026 demand - 2017 supply
Managers	1,5	1,3	-6,9
Professionals	2,2	2,3	0,0
Technicians and associate professionals	4,9	4,9	-3,7
Craft and related trades workers	8,2	6,5	-53,1
Plant and machine operators and assemblers	3,0	2,6	-14,5

Belgium	Excess AMT labour supply (thousand)		Required AMT labour supply growth (thousand)
	2017	2026	2026 demand - 2017 supply
Managers	2,8	3,0	1,9
Professionals	3,3	3,6	0,9
Technicians and associate professionals	4,6	5,1	4,8
Craft and related trades workers	7,2	6,8	-15,9
Plant and machine operators and assemblers	6,8	6,7	-9,2

Bulgaria	Excess AMT labour supply (thousand)		Required AMT labour supply growth (thousand)
	2017	2026	2026 demand - 2017 supply
Managers	1,6	1,4	-4,1
Professionals	1,7	2,1	4,6
Technicians and associate professionals	2,6	2,6	-1,4
Craft and related trades workers	12,5	11,4	-30,5
Plant and machine operators and assemblers	10,4	11,0	-0,8

Croatia	Excess AMT labour supply (thousand)		Required AMT labour supply growth (thousand)
	2017	2026	2026 demand - 2017 supply
Managers	1,6	1,7	-0,9
Professionals	2,0	2,3	0,7
Technicians and associate professionals	4,3	4,4	-3,2
Craft and related trades workers	9,2	8,8	-13,0
Plant and machine operators and assemblers	8,4	7,5	-16,4

Cyprus	Excess AMT labour supply (thousand)		Required AMT labour supply growth (thousand)
	2017	2026	2026 demand - 2017 supply
Managers	0,2	0,3	0,8
Professionals	0,2	0,3	0,6
Technicians and associate professionals	0,3	0,4	0,7
Craft and related trades workers	1,2	1,2	-0,9
Plant and machine operators and assemblers	0,5	0,5	-0,6

Czechia	Excess AMT labour supply (thousand)		Required AMT labour supply growth (thousand)
	2017	2026	2026 demand - 2017 supply
Managers	-0,6	-0,7	11,3
Professionals	-0,7	-0,8	2,9
Technicians and associate professionals	-2,3	-2,6	32,9
Craft and related trades workers	-4,5	-3,8	-69,2
Plant and machine operators and assemblers	-3,8	-3,6	-17,9

Denmark	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	0,5	0,5	-1,1
Professionals	2,1	2,5	6,5
Technicians and associate professionals	3,7	4,1	3,9
Craft and related trades workers	2,8	2,3	-13,6
Plant and machine operators and assemblers	2,7	2,5	-8,9

Estonia	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	0,5	0,5	0,3
Professionals	0,4	0,4	-0,8
Technicians and associate professionals	0,5	0,5	0,1
Craft and related trades workers	1,4	1,2	-5,4
Plant and machine operators and assemblers	1,5	1,4	-2,8

Finland	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	1,0	1,0	-0,9
Professionals	5,2	5,9	5,6
Technicians and associate professionals	3,6	3,8	-0,2
Craft and related trades workers	6,9	6,5	-13,1
Plant and machine operators and assemblers	4,2	4,7	2,7

France	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	24,7	27,3	5,1
Professionals	30,8	38,9	62,6
Technicians and associate professionals	66,6	70,3	-23,6
Craft and related trades workers	59,9	53,2	-137,5
Plant and machine operators and assemblers	67,9	62,6	-129,8

Germany	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	8,7	9,1	5,9
Professionals	22,2	25,4	123,7
Technicians and associate professionals	28,9	28,9	-28,9
Craft and related trades workers	50,8	45,6	-290,3
Plant and machine operators and assemblers	22,1	21,3	-57,9

Greece	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	3,4	4,6	0,9
Professionals	8,9	10,1	-4,5
Technicians and associate professionals	5,6	8,7	5,9
Craft and related trades workers	36,1	35,7	-37,3
Plant and machine operators and assemblers	16,6	18,9	-7,7

Hungary	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	0,6	0,6	3,0
Professionals	1,2	1,4	13,3
Technicians and associate professionals	1,3	1,5	7,2
Craft and related trades workers	4,2	3,5	-54,8
Plant and machine operators and assemblers	5,7	6,2	27,0

Ireland	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	1,5	1,9	3,3
Professionals	2,9	3,4	4,8
Technicians and associate professionals	2,0	2,1	-0,6
Craft and related trades workers	4,3	4,0	-9,5
Plant and machine operators and assemblers	2,9	2,9	-2,5

Italy	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	15,1	12,4	-40,5
Professionals	23,5	31,7	53,0
Technicians and associate professionals	94,2	103,0	-12,3
Craft and related trades workers	156,7	140,6	-306,5
Plant and machine operators and assemblers	87,8	83,2	-130,8

Latvia	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	0,7	0,9	2,2
Professionals	0,7	0,7	0,1
Technicians and associate professionals	0,7	0,9	1,4
Craft and related trades workers	3,0	2,9	-4,6
Plant and machine operators and assemblers	1,4	1,6	2,4

Lithuania	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	0,8	0,9	0,1
Professionals	1,1	1,1	-0,2
Technicians and associate professionals	0,8	0,8	0,7
Craft and related trades workers	4,6	3,8	-19,4
Plant and machine operators and assemblers	3,1	2,9	-5,0

Luxembourg	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	0,0	0,0	0,0
Professionals	0,1	0,1	0,6
Technicians and associate professionals	0,1	0,1	0,2
Craft and related trades workers	0,1	0,1	0,4
Plant and machine operators and assemblers	0,1	0,1	0,2

Malta	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	0,1	0,1	0,0
Professionals	0,0	0,0	0,3
Technicians and associate professionals	0,1	0,1	0,2
Craft and related trades workers	0,2	0,2	-0,2
Plant and machine operators and assemblers	0,1	0,1	-0,8

Netherlands	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	1,4	1,6	5,1
Professionals	3,5	3,8	8,0
Technicians and associate professionals	3,1	3,0	-6,9
Craft and related trades workers	5,8	5,0	-35,3
Plant and machine operators and assemblers	3,0	2,9	-6,7

Poland	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	8,9	10,5	30,0
Professionals	11,3	13,1	32,2
Technicians and associate professionals	17,3	16,5	-36,4
Craft and related trades workers	50,5	39,5	-326,4
Plant and machine operators and assemblers	29,8	30,3	-16,3

Portugal	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	3,9	4,3	0,6
Professionals	4,2	5,8	13,9
Technicians and associate professionals	8,1	8,4	-4,8
Craft and related trades workers	25,9	22,6	-63,0
Plant and machine operators and assemblers	20,5	20,2	-24,7

Romania	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	0,7	0,8	0,0
Professionals	6,1	6,6	8,9
Technicians and associate professionals	2,7	2,8	0,6
Craft and related trades workers	27,7	23,8	-132,5
Plant and machine operators and assemblers	18,0	19,8	31,1

Slovakia	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	1,5	1,8	2,8
Professionals	1,2	1,3	1,2
Technicians and associate professionals	5,9	6,7	3,7
Craft and related trades workers	15,1	15,0	-16,9
Plant and machine operators and assemblers	17,2	17,7	-11,1

Slovenia	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	0,7	0,9	2,8
Professionals	1,2	1,6	8,0
Technicians and associate professionals	1,3	1,5	3,6
Craft and related trades workers	3,9	4,0	-0,9
Plant and machine operators and assemblers	2,9	2,7	-7,3

Spain	Excess AMT labour supply (thousand) 2017	Excess AMT labour supply (thousand) 2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	24,2	28,9	-1,1
Professionals	37,3	49,1	20,5
Technicians and associate professionals	65,5	84,0	25,0
Craft and related trades workers	162,5	159,6	-176,7
Plant and machine operators and assemblers	115,6	122,0	-84,3

Sweden	Excess AMT labour supply (thousand) 2017	2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	1,9	2,0	0,1
Professionals	3,4	4,0	8,8
Technicians and associate professionals	6,4	6,2	-9,7
Craft and related trades workers	6,7	5,9	-22,1
Plant and machine operators and assemblers	5,1	4,6	-15,3

United Kingdom	Excess AMT labour supply (thousand) 2017	2026	Required AMT labour supply growth (thousand) 2026 demand - 2017 supply
Managers	9,1	9,0	-15,9
Professionals	13,8	14,5	17,9
Technicians and associate professionals	8,4	8,9	10,9
Craft and related trades workers	17,2	14,7	-119,1
Plant and machine operators and assemblers	9,9	8,8	-55,5

ANNEX F: REFERENCES

The current Annex offers an overview of publications and online sources that were used for the analysis.

F.1 Scientific publications

(1) Abele, E., Chryssolouris, G., Sihn, W., Metternich, J., El Maraghy, H., Hummel, V., Tisch, M., Ranz, F. (2015) "Learning factories for research, education, and training", Procedia CIPR, 32, pp. 1-6

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