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Curriculum Guidelines for Key Enabling Technologies (KETs) and Advanced Manufacturing Technologies (AMT)

INTERIM REPORT

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Curriculum Guidelines for Key Enabling Technologies (KETs) and Advanced Manufacturing Technologies (AMT)

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

2019

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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
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
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
UK	United Kingdom

Abbreviation	Full text
UNESCO	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

The Interim Report "Curriculum Guidelines for Key Enabling Technologies (KETs) and Advanced Manufacturing Technologies (AMT)" (2018-2019) has been prepared for the Executive Agency for Small and Medium-sized Enterprises (EASME) and the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs of the European Commission (DG GROW) in the framework of a new two-year European initiative aiming at increasing the quality and relevance of existing curricula. The work is carried out by PwC.

The Interim Report contains preliminary findings and conclusions elaborated during the first phase (January-November 2018) and is made public for stakeholder consultation, and specifically for collecting feedback and additional inputs that can be used in the second phase. The latter will focus on documenting best practices, engaging a broader ecosystem of stakeholders, designing European curriculum guidelines, and formulating recommendations. The Final Report, to be delivered at the end of the second phase, is scheduled to be released end of 2019/beginning of 2020.

Your remarks and suggestions for further improvement are welcome!

Context and objectives (sub-section 1.1)

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

The current initiative aims 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 21st Century needs. It involves data collection and research, design of guidelines, testing and validation, taking into account industry and market needs and best practices, based on contributions from key stakeholder groups. The initiative focusses on Vocational Education and Training, Higher Education and on-the-job training for AMT.

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 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 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 curriculum guidelines on a regular basis, as well as for recommendations on scaling up existing best practice efforts.

The target groups of this initiative are, on the one hand, higher education students and teachers, and on the other hand, workers and managers who need to acquire continuously new specialised skills related to AMT. Stakeholder engagement is 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.

Project design and report structure (sub-sections 1.2 – 1.3)

The tasks of this initiative are grouped into three Work Packages corresponding to the two main phases of twelve months each. The first phase was dedicated to research, collection and analysis of latest information and data, based on desk research, expert workshops and interviews with key stakeholders. This interim report, presenting the results of the analysis and the state-of-play in the EU on education and training for AMT, signifies the end of this phase. The interim report will later be integrated into the final report.

The second phase will concentrate on documenting best practices, engaging a broader ecosystem of stakeholders, designing European curriculum guidelines and quality labels for AMT, and formulating recommendations. A final report will be delivered at the end of this phase.

The interim report presents the key findings from the activities performed during the first phase of the initiative, and specifically in the period from January 2018 until November 2018. The report first provides an overview of the latest technological trends and market developments for AMT, and addresses the key needs in terms of skills, education and on-the-job training. Furthermore, it contains a state-of-play analysis of the key players in AMT-related education and training in Europe, as well as an overview of the relevant strategies, policies and initiatives at national and EU levels to address the situation regarding the education and training curricula. The report also provides an overview of the key publications in this field, as well as sample descriptions of good practice curricula, and the key barriers for the successful transformation of the AMT-related education and training system. Finally, the report offers inputs for a draft proposal for the curriculum guidelines, and addresses the identified challenges, mitigation measures and proposed solutions.

Latest technological trends and market developments for AMT (sub-sections 2.1 – 2.3)

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 (sub-sections 3.1 – 3.3)

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 students 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 employees and exploring new/alternative forms of education and training.

Key players in AMT education & training in Europe (sub-section 4.1)

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 Small and Medium-Sized Enterprises.

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 (sub-sections 4.2 - 4.4)

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 (sub-section 4.5)

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 students/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.

Towards a proposal for curriculum guidelines (sub-sections 5.1 – 5.3)

The current initiative specifically aims to produce curriculum guidelines for Europe’s education and training organisations, highlighting the key points of attention and good practice examples for aligning their approach with the 21st Century needs. The guidelines will be developed based on the extensive state-of-play analysis and active stakeholder contribution. The aim is to follow a holistic approach covering a broad spectrum of dimensions relevant to curriculum design and implementation. Specifically, the following eight dimensions will be considered by the analytical framework: (1) Strategy; (2) Collaboration; (3) Content; (4) Learning environment; (5) Delivery mechanisms; (6) Assessment; (7) Recognition; (8) Quality.

1. INTRODUCTION

This document represents the Interim 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 Interim Report presents the key findings from the activities performed during the first phase of the Curriculum Guidelines initiative, and specifically in the period from January 2018 until November 2018. The Interim Report first provides an overview of the latest technological trends and market developments for AMT[1], and addresses the key needs in terms of skills, education and on-the-job training. Furthermore, it contains a state-of-play analysis of the key players in AMT-related education and training in Europe, as well as an overview of the relevant strategies, policies and initiatives at national and EU levels to address the situation regarding the education and training curricula. The report also provides an overview of the key publications in this field, as well as sample descriptions of good practice curricula, and the key barriers for the successful transformation of the AMT-related education & training system. Finally, the report offers inputs for a draft proposal for the curriculum guidelines, and addresses the identified challenges, mitigation measures and proposed solutions.

The Interim Report contains preliminary findings and conclusions. The final version of the findings and conclusions will be provided in the Final Report that is scheduled to be released in the end of 2019.

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

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[2]. Advanced Manufacturing Technologies (AMT), 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[3]. 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.

1 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.
2 See, for example, http://www.eurekanetwork.org/content/smart-advanced-manufacturing
3 UKCES (2012) "Sector Skills Insights: Advanced Manufacturing", Evidence Report 48, available at: http://dera.ioe.ac.uk/15961/1/evidence-report-48-advanced-manufacturing.pdf

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[4]:

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

These developments have **direct implications for the skill needs**. The AMT professionals need to possess skills related to, among others, digital technologies, analytical thinking, machine ergonomics, as well as understanding manufacturing technologies (including design for manufacturing, design for assembly and design for automation). The AMT domain also heavily relies on skills linked to merging and adaptation of technologies. Examples include merging laser technologies with printing techniques, rapid prototyping technologies with tissue scaffolding etc. Similar skills become increasingly needed also by lower levels in organisations, to be innovative about implementing process and technique changes. This also relates to management skills needed to recognise, understand and manage change[5].

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

4 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, available at: https://institute.unido.org/wp-content/uploads/2017/06/emerging_trends_global_manufacturing.pdf

5 *Ibid*.

6 European Commission (2014) "EU Skills Panorama: Focus on Advanced Manufacturing", available at: http://skillspanorama.cedefop.europa.eu/sites/default/files/EUSP_AH_AdvManufacturing_0.pdf

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]. However, these estimates should be treated with caution, as the numbers vary per source and methodology.

A comparable analysis has recently been performed for the United States (the U.S.). According to a new 2018 skills gap study[9] from Deloitte and The Manufacturing Institute, the manufacturing skills gap in the U.S. is expected to grow from about 488,000 jobs left open today to 2.4 million manufacturing jobs going unfilled between 2018 and 2028 (compared to 2 million jobs between 2015 and 2025 per an earlier study)[10]. The key reason for this workforce shortage is reported to be attributed to the skills gap crisis[11].

The abovementioned challenges signify **a need to reconsider the current approach towards the education and training[12] 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.

To this end, EASME and DG GROW of the European Commission have recently launched a new initiative for developing **"Curriculum Guidelines for Key Enabling Technologies (KETs) and Advanced Manufacturing Technologies (AMT)"**. This initiative aims 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 21st Century needs. It involves data collection and research, design of guidelines, testing and validation, taking into account industry and market needs and best practices, based on contributions from key stakeholder groups. The initiative focusses on **Vocational Education and Training (VET), Higher Education and on-the-job training for AMT**.

7 European Commission (2014) "EU Skills Panorama: Focus on Advanced Manufacturing", available at: http://skillspanorama.cedefop.europa.eu/sites/default/files/EUSP_AH_AdvManufacturing_0.pdf
8 *Ibid*.
9 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, available at: http://www.themanufacturinginstitute.org/Research/Skills-Gap-in-Manufacturing/~/media/E100A553E4884F40B2241C1379C7D6C4.ashx
10 Crowe S. (2018) "Skills gap worsening in US manufacturing industry", published on 21 November 2018 in The Robot Report, available at: https://www.therobotreport.com/skills-gap-worsening-manufacturing/
11 *Ibid*.
12 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 are being explored:

Teaching[13] 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[14];
- 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.

The outcome of this initiative will play a prominent role in forming the EU policy making regarding upskilling of the AMT workforce.

1.1.2. General objective

The current initiative aims at the development, promotion and implementation of pan-European curriculum guidelines (with proposals for relevant quality labels) for AMT. The overall objective of this service contract is **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 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 thus need to develop a common vision that is supported by all key stakeholder groups.

The initiative involves data collection and research, design of guidelines, testing and validation, taking into account industry and market needs, best practices, and contributions from 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

13 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/)

14 For more information, see section 3.2.4.

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, on the one hand, higher education students and teachers, and on the other, workers and managers (especially those employed by SMEs) who need to acquire continuously new specialised skills related to AMT.

We aim to follow a demand-led (industry-driven) and results-oriented approach, and further draw on best practices and achievements related to the design and implementation of AMT curricula. The outcomes of this initiative will contribute to the efforts of the European Commission and Member States to facilitate the successful implementation of the "New Skills Agenda" and of the European industrial policy[15].

Stakeholder engagement is 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. We aim to involve all key relevant stakeholder groups including representatives of VET, Higher Education, industry and research, on-the-job training providers, policy makers and supporting structures such as education/training and industry associations, multi-stakeholder partnerships etc.

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 KETs and AMT and - based on these needs - (2) the most relevant educational and training curricula and their delivery (including learning factory, e-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;
- Designing detailed EQAVET-compatible pan-European guidelines and quality labels for new curriculum development for KETs and 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 and quality labels;

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15 https://ec.europa.eu/growth/industry/policy_en

- Drafting and delivering the final report, presenting the state-of-play, best practices, curriculum guidelines and quality labels, formulated recommendations, and a roadmap for promotion and implementation of "Curriculum guidelines for KET and AMT skills in Europe";
- 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 will 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 (curriculum guidelines and quality labels);
- Create a feedback loop between policy makers, business and social leaders and SMEs;
- Improve the relevance and quality of curricula for AMT skills development;
- Contribute to the further development and improvement of European and national initiatives on AMT skills.

To measure the quality of the results at the end of the work, the **key indicators** include:

- Quality of the analysis of the situation and of the description of the state-of-the-art;
- Quality of the selection and analysis of best practices;
- Quality of the proposed curriculum guidelines and quality labels;
- Level of support from academia, industry and policy makers for the guidelines and quality labels;
- Impact on national policy making;
- Number of stakeholders and countries engaged and supporting the results;
- Number of follow-up initiatives at the EU, national and regional levels;

Specific **performance indicators** also include:

- Management of the work-packages and tasks to planned milestones;
- Timely status updates to stakeholders;
- Timely and successful organisation of the workshops and the conference;
- Number of and attendance at the expert workshops and the conference;
- Compliance with project aims, scheduling and budget;
- Timely delivery of results, reports on progress and deliverables.

1.1.5. Project design

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

The **first phase** was dedicated to research, collection and analysis of latest information and data, based on desk research, expert workshops and interviews with key stakeholders. An interim report, presenting the results of the analysis and the state-of-play in the EU on education & training for AMT, signifies the end of this phase. The interim report will later be integrated into the final report.

The **second phase** will concentrate on documenting best practices, engaging a broader ecosystem of stakeholders, designing European curriculum guidelines and quality labels for AMT, and formulating recommendations. A final report will be delivered at the end of this phase. This report aims to provide a solid basis for action at the EU and national levels.

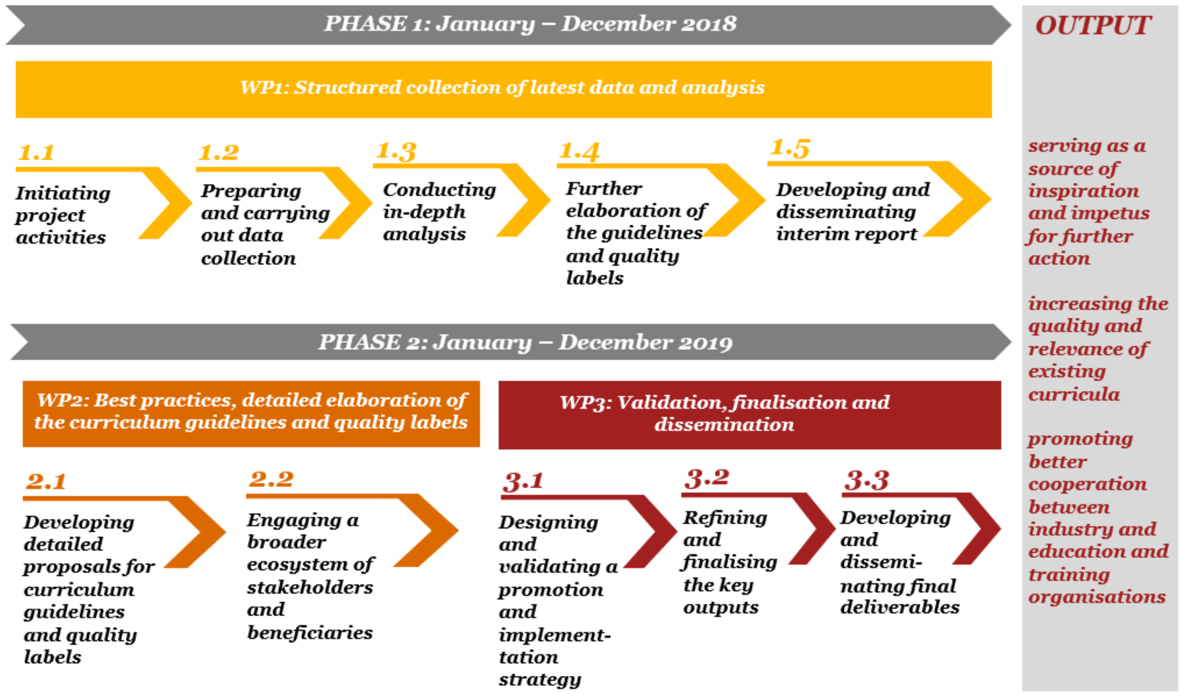

FIGURE 1-1: Project design

1.2. Activities performed so far

A detailed overview of performed activities is available in bi-monthly progress reports. The current section aims to summarise the key developments. The activities performed during the first phase of this initiative correspond to the activities of WP1 "Structured collection of latest data and analysis", consisting of five distinctive but interrelated tasks.

1.2.1. Task 1.1: Initiating project activities

The current task implied organising a kick-off meeting, developing an Inception Report, setting up a Steering Committee (SC) and creating an informal Key Stakeholder Group (KSG).

The kick-off meeting took place on 16 January 2018, with an objective to fine-tune the approach and planning, and develop the Inception Report. The latter was delivered by the project team to the Commission/EASME on 29 January 2018, and is available as a separate document.

Within the first weeks of the initiative, the SC was set up to guide the work of the project team. It is composed of five experts renowned in the fields of education and training, KETs and AMT (with a particular focus on skills in these domains), as well as digital transformation and industrial modernisation. The SC will review the interim and final reports and attend dedicated SC meetings in Brussels.

The KSG refers to a community of highly qualified external experts that are engaged in the current initiative by means of workshops, in-depth interviews, online surveys and other ways of stakeholder consultation. When setting up the group, we aimed for a good representativeness of multiple stakeholder groups, a good geographical balance and a good gender balance. This group is constantly expanding, with new contacts being added in the course of the initiative. At this moment, the KSG consists of more than 120 experts.

1.2.2. Task 1.2: Preparing and carrying out data collection

Task 1.2 implied preparing and collecting through multiple means the latest information and data with a view to provide a clear, well-structured and comprehensive description of the state-of-the-art concerning AMT-related education & training offer in Europe. This task implied reviewing the relevant information to constitute an initial solid basis of evidence and facilitate further collection of new material.

Within this Task, an extensive scan of relevant desk-research resources (per topic of analysis) was performed, including sources recommended by stakeholders. This task included actual data collection activities related to the latest technological trends and market developments for AMT; key needs in terms of skills, education and training; sample description of good practice curricula; and strategies, policies and initiatives to improve and update curricula. Detailed desk-research was performed for each specific topic of analysis, complemented by in-depth interviews and consultations with more than 30 representatives of multiple EU Member States and key experts in the field of AMT-related education & training. These activities were complemented by two expert workshops.

The first expert workshop, held in Brussels on 12 June 2018, focussed on **new/alternative approaches to Higher Education in AMT, and specifically Bachelor and Master Programmes**. 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 & training to make an impact. Education & training elements can also be embedded into broader programmes, as a compulsory element. A detailed workshop report is available in a separate document.

In the context of the state-of-play analysis, based on desk-research, in-depth interviews, multiple email and phone consultations with key experts and the first expert workshop, the project team has accumulated an extensive knowledge base. This knowledge base was then systemised, clustered and translated into a **curriculum guidelines framework**. The framework serves as a structure for the detailed curriculum guidelines for Europe’s education & training organisations, aiming to highlight the key points of attention and good practice examples, when it comes to aligning their approach with the 21st Century needs. The aim is to follow a holistic approach covering a broad spectrum of dimensions relevant to curriculum design and implementation. In total, 54 experts were approached with a request to provide their inputs for the specific elements of the framework (such as good practice examples and relevant data sources). These experts were provided with a detailed curriculum guidelines framework template. More information on the framework and the collected inputs is available in Chapter 5 of this report.

Additionally, an **online survey** is currently under development, and it is scheduled to be launched in December 2018, with a duration of two months. The objective of the online survey will be to validate the initial findings and set priorities for the curriculum guidelines that are to be further developed within the second phase.

1.2.3. Task 1.3: Conducting in-depth analysis

Based on the accumulated knowledge base, an extensive **data analysis** was performed including an overview of the latest technological trends and market developments for AMT, and the key needs in terms of skills, education and on-the-job training. Furthermore, a state-of-play analysis of the key players in AMT-related education and training in Europe was developed, complemented by an overview of the relevant strategies, policies and initiatives at national and EU levels to address the situation regarding the education and training curricula. We also prepared an overview of the key publications in this field, as well as sample descriptions of good practice curricula, and an overview of the key barriers for the successful transformation of the AMT education & training domain. Finally, a draft proposal for the curriculum guidelines was developed.

The second expert workshop, held in Brussels on 18 September 2018, addressed **the initiatives and approaches aiming to improve curricula/learning strategies for <u>on-the-job training</u> in AMT**. The workshop featured good practice examples and practical illustrations of the proposed solutions from employers (both large and small companies). The workshop particularly aimed to offer a discussion platform to address key challenges and actions that would need to be introduced at the EU level. During the workshop, it was emphasised that there is a need to evaluate the scalability and the sustainability of good practice examples. There is also 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. Motivation of the learner was highlighted as the key factor for successful upskilling/reskilling. The role of education and training is to cultivate motivation in learners. A detailed workshop report is available in a separate document.

1.2.4. Task 1.4: Further elaboration of the curriculum guidelines and quality labels

This task implied further elaboration of the initial proposal and framework for curriculum guidelines, developed within previous tasks. This elaboration was based on the outputs of the second expert workshop, as well as additional analytical work and consultation with external experts. The initial work on quality labels was performed in the context of one of the dimensions of the curriculum guidelines framework, explicitly focussing on quality. The results of this exercise are presented in Chapter 5 of this report.

Within this Task, the third expert workshop will be organised in Brussels on 13 December 2018, and it will focus on **the initiatives and approaches aiming to improve curricula/learning strategies for AMT-related non-tertiary[16] vocational education**.

1.2.5. Developing and disseminating interim report

Task 1.5 implied developing a draft Interim Report and organising a SC meeting with the Commission/EASME. The SC meeting is scheduled for 20 November 2018 in Brussels. The aim of the meeting will be to discuss the feedback collected from each of the SC members and identify the approach for finalising the Interim Report.

1.3. Report structure

The Interim 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 an overview 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 provides an overview of the key publications in this field, as well as sample descriptions of good practice curricula, and the key barriers for the successful transformation of the AMT education & training domain. **Chapter 5** offers a draft proposal for the curriculum guidelines. **Chapter 6** addresses the identified challenges, mitigation measures and proposed solutions, as well as the next steps.

Annex A contains a list of stakeholders that have been consulted so far by means of workshops and in-depth interviews/individual expert consultation. **Annex B** offers illustrative examples of new/alternative approaches towards education & training in KETs and AMT. **Annex C** provides a detailed overview of the key technological developments within AMT and contains the resulting implications for curriculum requirements. **Annex D** offers an overview of abstracts from relevant scientific, policy and business publications. Finally, **Annex E** contains good practice curricula descriptions.

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

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[17]. It builds on *a wide range of new technologies* to create value through seamlessly generating, analysing and communicating data.

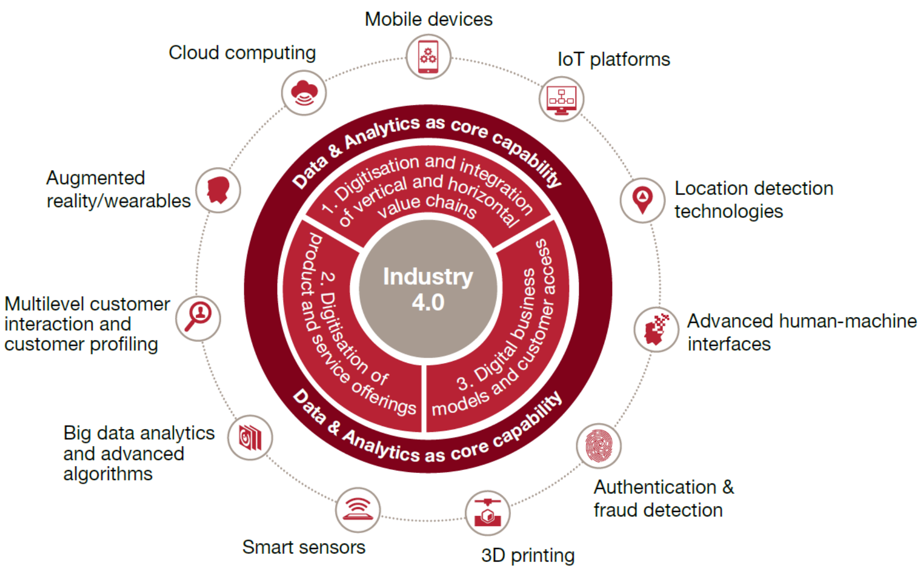

Figure 2-1: Industry 4.0 framework and contributing digital technologies[18]

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[19]. 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 systems and growth of analytics and AI-enabled systems are expected to be the driving

17 PwC (2016) "Industry 4.0: Building the digital enterprise", available at: https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf

18 *Ibid*.

19 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", from https://www.grandviewresearch.com/industry-analysis/smart-manufacturing-market

growth factors for AMT for years to come[20]. Figure 2-1 provides an overview of some key technologies contributing to Industry 4.0.

The following three key technological developments can be distinguished within Industry 4.0[21]:

(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 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)[22].

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.

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20 PwC (2016) "Industry 4.0: Building the digital enterprise", available at: https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf

21 *Ibid*.

22 Advanced Manufacturing National Program Office. (n.d.) "Glossary of Advanced Manufacturing Terms". Retrieved October 13, 2018, from https://www.manufacturing.gov/glossary

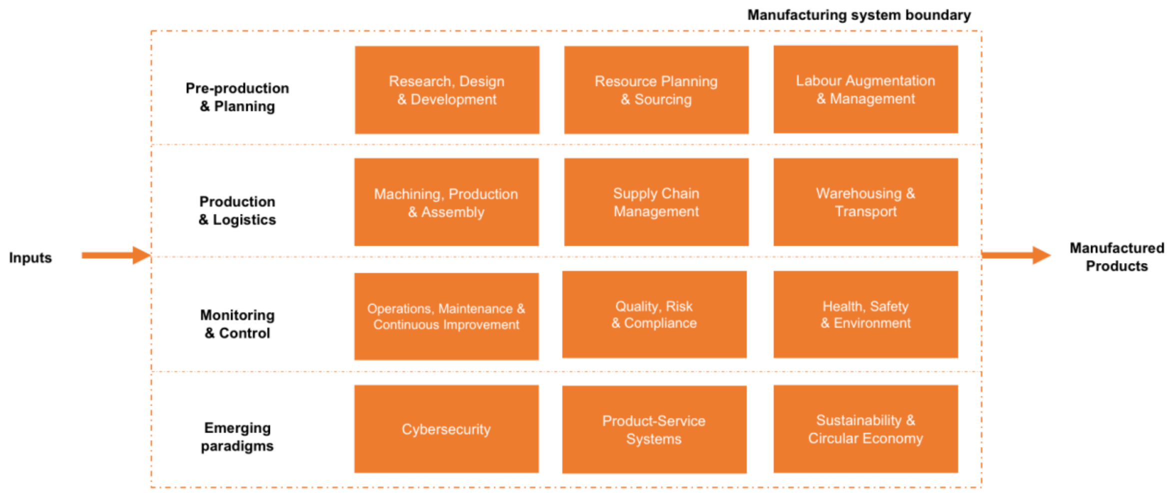

Figure 2-2: Areas for technological enhancement in the context of Advanced Manufacturing

2.2. Overview of key market developments

According to the report by Mordor Intelligence[23], the Global Smart Manufacturing market was estimated at 211.97 billion USD (185.54 billion EUR[24]) in 2017, and it is expected to reach a value of 595.29 billion USD (521.07 billion EUR[25]) by 2023 at a Compound Annual Growth Rate (CAGR) of 18.78%, during the forecast period of 2018-2023[26]. The report by MarketsandMarkets[27] provides somewhat less ambitious figures, and values the smart manufacturing market at 153.25 billion USD (134.14 billion EUR[28]) in 2017, while forecasting that it will reach 299.19 billion USD (261.89 billion EUR[29]) by 2023, at a CAGR of 11.9% from 2018 to 2023[30]. At the same time, Grand View Research[31] estimated the global smart manufacturing market size to reach 395.2

23 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, available at: https://www.mordorintelligence.com/industry-reports/smart-manufacturing-market

24 Based on the google currency converter of 27 October 2018

25 *Ibid*.

26 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.

27 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, available at: https://www.marketsandmarkets.com/Market-Reports/smart-manufacturing-market-105448439.html?gclid=EAIaIQobChMIzfTPrLSm3gIVieJ3Ch1_HgQnEAAYASAAEgK57_D_BwE

28 Based on the google currency converter of 27 October 2018

29 Based on the google currency converter of 27 October 2018

30 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.

31 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, available at: https://www.grandviewresearch.com/industry-analysis/smart-manufacturing-market

billion USD (345.92 billion EUR[32]) by 2025, which is somewhere in between the estimates of the abovementioned other two sources. The estimates of Zion Market Research[33] suggest that the global smart manufacturing market was valued at around 152.3 billion USD (133.31 billion EUR[34]) in 2017 and is expected to reach approximately 479.01 billion USD (419.28 billion EUR[35]) 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.

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 solution - designed to overcome the modern-day production challenges - also to SMEs[36].

Key **customer demand trends** include[37]:

- 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[38]:

- 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.

32 Based on the google currency converter of 27 October 2018

33 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, available at: https://globenewswire.com/news-release/2018/05/16/1507510/0/en/Global-Smart-Manufacturing-Market-Will-Reach-USD-479-01-Billion-by-2023-Zion-Market-Research.html

34 Based on the google currency converter of 27 October 2018

35 *Ibid*.

36 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, available at: https://www.mordorintelligence.com/industry-reports/smart-manufacturing-market

37 UNIDO (2017) "Emerging trends in global advanced manufacturing: Challenges, opportunities and policy responses", available at: https://institute.unido.org/wp-content/uploads/2017/06/emerging_trends_global_manufacturing.pdf

38 *Ibid*.

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[39].

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[40].

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[41]. 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[42]. 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[43].

Various European countries including Germany, France, the United Kingdom, are also among the leading developers and adopters of smart manufacturing

39 Research and Markets (2018) "Smart Manufacturing Market, 2025", published on 24 January 2018, available at: https://www.prnewswire.com/news-releases/smart-manufacturing-market-2025-300587394.html

40 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, available at: https://www.grandviewresearch.com/industry-analysis/smart-manufacturing-market

41 *Ibid*.

42 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, available at: https://globenewswire.com/news-release/2018/05/16/1507510/0/en/Global-Smart-Manufacturing-Market-Will-Reach-USD-479-01-Billion-by-2023-Zion-Market-Research.html

43 *Ibid*.

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)[44].

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[45]. 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[46]. Some European 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[47].

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"[48], realities of modern learners[49], 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.

44 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, available at: https://globenewswire.com/news-release/2018/05/16/1507510/0/en/Global-Smart-Manufacturing-Market-Will-Reach-USD-479-01-Billion-by-2023-Zion-Market-Research.html

45 PwC (2018) "How industry leaders build integrated operations ecosystems to deliver end-to-end customer solutions", Digital Operations Study 2018, available at: https://www.strategyand.pwc.com/media/file/Global-Digital-Operations-Study_Digital-Champions.pdf; cited in McGee P. (2018) "Europe risks falling behind in digital transformation", published in Financial Times on 5 June 2018, available at: https://www.ft.com/content/9b5c24fa-5df6-11e8-ab47-8fd33f423c09

46 McGee P. (2018) "Europe risks falling behind in digital transformation", published in Financial Times on 5 June 2018, available at: https://www.ft.com/content/9b5c24fa-5df6-11e8-ab47-8fd33f423c09

47 *Ibid*.

48 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

49 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.

Specific relevant **labour market trends** include the following[50]:

- 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[51] 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[52].
- 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.
- 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[53]:

- The emergence of a wide variety of employment situations[54];

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50 WEC (2016) "The future of work: White paper from the employment industry", World Employment Confederation Europe, September 2016, available at: https://www.wecglobal.org/fileadmin/templates/ciett/docs/WEC___The_Future_of_Work_-_What_role_for_the_employment_industry.pdf

51 OECD (2014) "Education at a glance", available at: http://www.oecd.org/education/Education-at-a-Glance-2014.pdf

52 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

53 WEC (2016) "The future of work: White paper from the employment industry", World Employment Confederation Europe, September 2016, available at: https://www.wecglobal.org/fileadmin/templates/ciett/docs/WEC___The_Future_of_Work_-_What_role_for_the_employment_industry.pdf

54 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

- 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)[55] 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[56]**.

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[57].

With regard to generational factors, **Millennials** are predicted to comprise 75 percent of the global workforce by 2025[58]. According to Sodexo 2017 Global Workplace Trends[59], 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[60]**. They are often referred to as "overeducated, but underskilled". Additionally, Millennials tend to demonstrate a lack of loyalty to their employers. Nevertheless, these 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.

55 WEF (2016) "The Future of Jobs", available at: http://reports.weforum.org/future-of-jobs-2016/employment-trends/
56 *Ibid*.
57 *Ibid*.
58 https://www2.deloitte.com/content/dam/Deloitte/global/Documents/About-Deloitte/gx-dttl-2014-millennial-survey-report.pdf
59 https://www.sodexo.com/home/media/publications/studies-and-reports/2017-workplace-trends/unlocking-millennial-talent.html
60 See, for example, MindEdge (2017) "Online Survey of Critical Thinking Skills", available at: https://mindedge.com/page/dig-deeper

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 AMT professionals. In general, there is a need for creating hands-on opportunities within education systems; close collaboration of business and educational institutions; offering students 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 employees. In the current chapter, we zoom into the key needs in terms of skills, education and training.

3.1. Key needs in terms of skills

In this sub-section, we first address the skill requirements for KETs 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 KETs professionals

An extensive analysis of skill requirements for KETs 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[61]. 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[62].

The state-of-the-art skills research, as well as prominent frameworks on skills[63], suggest that the notion of skills goes hand in hand with the notions of competency, knowledge, attitudes and values[64].

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[65].

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

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61 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

62 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).

63 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.

64 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

65 CEDEFOP (2006) "Typology of knowledge, skills and competences: Clarification of the concept and prototype", CEDEFOP reference series.

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[66].

Competency, in turn, can be defined as one's capability to handle certain situations successfully or complete a job[67]. 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[68].

The following six categories of KETs competencies were identified[69]:

(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[70]**: competencies related to management, administration, IP and finance (e.g. strategic analysis, marketing, project management, R&D management, IP management);
(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).

KETs 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 KETs. However, the competencies needed to successfully operate within KETs go far beyond the technical field and also cover a wide range of non-technical/transversal areas. These non-technical competency areas include competences related to quality, risk & safety;

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66 CEDEFOP (2006) "Typology of knowledge, skills and competences: Clarification of the concept and prototype", CEDEFOP reference series.

67 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.

68 OECD (2018) "The Future Education and Skills: Education 2030", available at: https://www.oecd.org/education/2030/E2030%20Position%20Paper%20(05.04.2018).pdf

69 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

70 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 Commission, available at: http://eskills-scale.eu/fileadmin/eskills_scale/all_final_deliverables/scale_e-leadership_agenda_final.pdf). While 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.

management & entrepreneurship; communication; innovation-related competences and emotional intelligence.

With regard to quality, risk & safety, KETs present 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 KETs, including high-risk product demonstration and proof-of-concept projects, 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 KETs, 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 KETs (which are typically formed from people with diverse professional and cultural backgrounds), **communication-related competencies** represent another key competence category for KETs. 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 KETs 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 KETs, 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 KETs 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 KETs workers, independently of the respective KET, 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 KETs. Specific KETs competences, in turn, are unique to a particular KET, employer and/or a specific job profile. These competences, 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 KETs-related domains (e.g. specific legislation, specific sales techniques, detailed quality assurance principles etc.)[71].Furthermore, a highly complex multidisciplinary

71 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

nature of KETs 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 working in KETs. The required competencies can be to a different extent present in different individuals, that, in turn, need to work together and complement each other. KETs 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 KETs, particularly when it comes to specific application areas[72].

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)[73], 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.

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.

Technologies", prepared for DG GROW of the European Commission, Service contract nr. SI2.ACPROCE060233200

72 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

73 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, available at: http://www.vdi.eu/fileadmin/vdi_de/redakteur/karriere_bilder/VDI-ASME__2015__White_Paper_final.pdf

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[74] from Deloitte and The Manufacturing Institute, analysing the situation in the U.S.[75]. 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 skills, programming skills for robots/ automation, working with tools and technology, and critical thinking skills[76].

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

74 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, available at: http://www.themanufacturinginstitute.org/Research/Skills-Gap-in-Manufacturing/~/media/E100A553E4884F40B2241C1379C7D6C4.ashx

75 Crowe S. (2018) "Skills gap worsening in US manufacturing industry", published on 21 November 2018 in The Robot Report, available at: https://www.therobotreport.com/skills-gap-worsening-manufacturing/

76 *Ibid*.

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[77].

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.[78].

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.

77 CECIMO (2013) The European machine tool industry's Manifesto on skills, September 2013
78 *Ibid*.

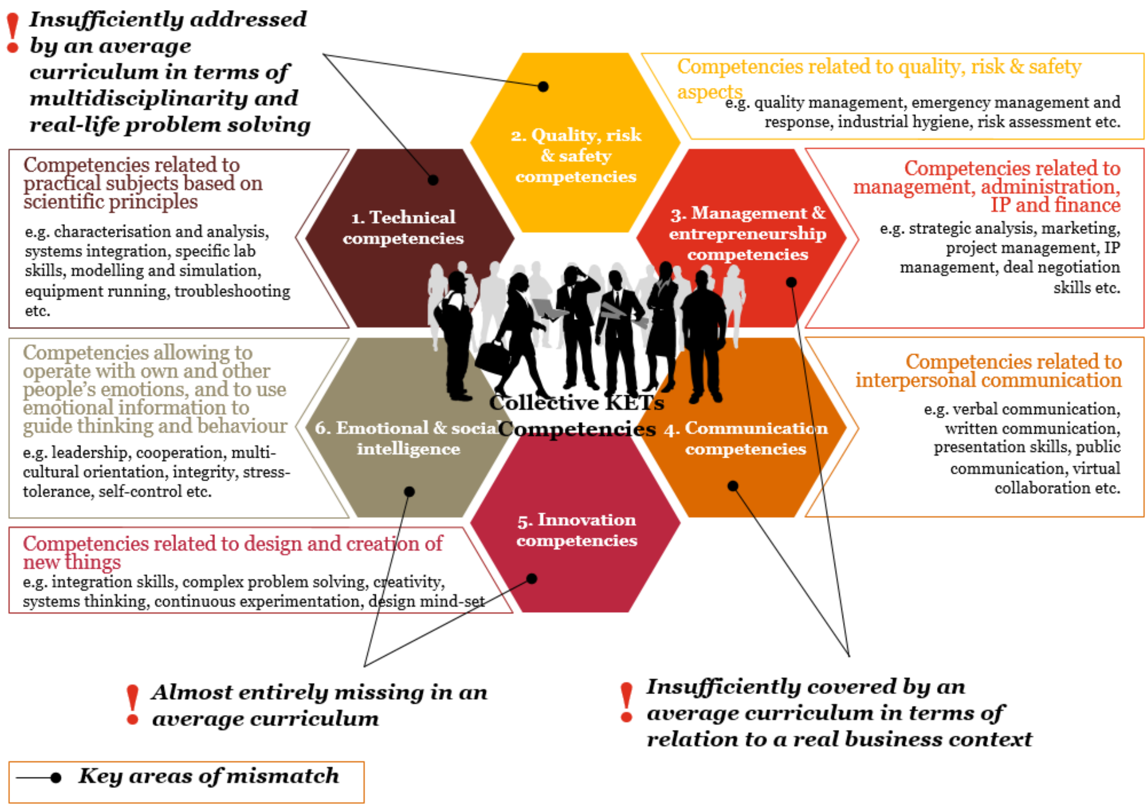

FIGURE 3-1: Collective KETs competencies and key areas of mismatch (source: PwC[79])

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*[80]). 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. 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[81].

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79 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

80 See, for example, T-Summit that was held in Washington DC (USA) in 2016, available at: http://tsummit.org/t

81 Based on Rotherham A.J. and Willingham D. (2009) "21st Century Skills: The Challenges Ahead"; available at: http://www.ascd.org/publications/educational-leadership/sept09/vol67/num01/21st-Century-Skills@-The-Challenges-Ahead.aspx

Many stakeholders argue that with so much new knowledge being created, content no longer matters. The ways of knowing information are now much more important than 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/ professionals and employers. **There is a need to teach skills in the context of particular content/knowledge and to treat both as equally important**[82].

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 students will actually be learning them. There needs to be clarity on which methods and techniques are best in training these skills in students[83]. In this respect, the potential of **technology-enabled learning tools** (e.g. e-learning, including MOOCs, mlearning, 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[84], 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);
    - In order to ensure multidisciplinarity in education, a concept of **'dual learning'**[85] 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 competences and emotional intelligence skills;
    - **Adding Arts to the curriculum**: competences coming from STEM are not sufficient for KETs. KETs require STEAM[86], with Arts included, which refers to creativity that can lead to innovations. Arts and creativity therefore should also be embedded in technical curricula.

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82 Based on Rotherham A.J. and Willingham D. (2009) "21st Century Skills: The Challenges Ahead"; available at: http://www.ascd.org/publications/educational-leadership/sept09/vol67/num01/21st-Century-Skills@-The-Challenges-Ahead.aspx

83 *Ibid.*

84 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, available at: http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=8764

85 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.

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

- **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 & 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 & 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;
  - Engaging students in assessing teachers' performance[87].

(2) **Multidisciplinary orientation**: enhancing the KETs-/AMT-related technical courses with the elements that stimulate analytical and critical thinking,

87 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

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, mlearning, 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**[88].

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[89].

Existing research suggests that **many teachers do not need to be convinced that innovative approaches to learning are a good idea – they already believe that**[90]. 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

88 Based on Rotherham A.J. and Willingham D. (2009) “21st Century Skills: The Challenges Ahead”; available at: http://www.ascd.org/publications/educational-leadership/sept09/vol67/num01/21st-Century-Skills@-The-Challenges-Ahead.aspx

89 *Ibid*.

90 *Ibid*.

methods[91]. 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[92].

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[93]. 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.

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 competences when it comes to technical specialisation, practical and transversal skills[94]. 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 competences 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 work in teams and through mentoring by senior colleagues[95]. 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[96], including human and intellectual resources to provide such training.

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91 Based on Rotherham A.J. and Willingham D. (2009) "21st Century Skills: The Challenges Ahead"; available at: http://www.ascd.org/publications/educational-leadership/sept09/vol67/num01/21st-Century-Skills@-The-Challenges-Ahead.aspx
92 *Ibid*.
93 *Ibid*.
94 See CECIMO (2013) The European machine tool industry's Manifesto on skills, September 2013
95 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, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2273088
96 CECIMO (2013) The European machine tool industry's Manifesto on skills, September 2013

Small companies can therefore hardly provide the necessary training themselves, and heavily rely on partnerships with local providers of training and local authorities[97]. 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[98].

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[99].

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[100] 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 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[101]. 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[102].

97 "Skills Development and Training in SMEs", OECD Skills Studies 2013
98 *Ibid*.
99 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, available at: http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=8764
100 Bersin by Deloitte (2015) "Meet the modern learner" infographic, available at: https://mrmck.wordpress.com/2015/06/19/meet-the-modern-learner-infographic/
101 Basu S. (2017) "5 Technology-Enabled Learning Trends In 2017", published in eLearning Industry on 15 February 2017, available at: https://elearningindustry.com/5-technology-enabled-learning-trends-2017
102 *Ibid.*

The technology-enabled learning trends that will have a significant impact on the workplace learning ecosystem include the following[103].

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**[104].

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[105]. 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 mlearning 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 mlearning programs becomes more affordable than other alternatives. Furthermore, mlearning also allows employees to feel an extra level of responsibility for their training, since their training modules are literally always in their hands[106].

There is a common misconception that mlearning 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[107].

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". Virtual/Augmented Reality (VR/AR), as it has the ability to close infrastructure gaps, will have an increasing impact on how organisations can achieve

103 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.

104 Basu S. (2017) "5 Technology-Enabled Learning Trends In 2017", published in eLearning Industry on 15 February 2017, available at: https://elearningindustry.com/5-technology-enabled-learning-trends-2017

105 Emerson M. (2015) "How to Handle Employee Training in Your Small Business", published on 10 November 2015, available at: https://succeedasyourownboss.com/how-to-handle-employee-training-in-your-small-business/

106 Balls A. (2017) "Why Use Mobile Learning for a Multigenerational Workforce", published on AllenComm on 30 November 2017, available at: https://www.allencomm.com/blog/2017/11/mobile-learning-workforce/

107 Balls A. (2017) "Why Use Mobile Learning for a Multigenerational Workforce", published on AllenComm on 30 November 2017, available at: https://www.allencomm.com/blog/2017/11/mobile-learning-workforce/

that[108]. Some companies are now using VR/AR technologies to increase sales effectiveness, educate customers, and establish brand recall. Different VR/AR cases and requirements re expected to emerge over several other areas in the coming years[109].

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[110].

Need to make learning engaging

Gamification has proved to be an effective strategy for employee engagement[111]. 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[112].

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[113]. 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[114].

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

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[115].

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

108 Basu S. (2017) "5 Technology-Enabled Learning Trends In 2017", published in eLearning Industry on 15 February 2017, available at: https://elearningindustry.com/5-technology-enabled-learning-trends-2017
109 *Ibid*.
110 My Smart Gadget (2016) "Virtual reality for small business", published on 16 September 2016, available at: https://mysmartgadget.com/virtual-reality-for-small-business/
111 Richardson A. (2017) "Gamification: A Valuable Employee Engagement Strategy", Aspire Blog, 13 February 2017, available at: https://www.psaspire.com/aspire-blog/employee-engagement-strategy/gamification/
112 *Ibid*.
113 Watson Z. (2014) "5 Gamification Companies for Small Businesses", published on Technology Advice on 26 March 2014, available at: https://technologyadvice.com/blog/marketing/gamification-for-small-businesses/
114 *Ibid*.
115 Basu S. (2017) "5 Technology-Enabled Learning Trends In 2017", published in eLearning Industry on 15 February 2017, available at: https://elearningindustry.com/5-technology-enabled-learning-trends-2017

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[116].

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)[117].

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[118]. 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[119]. 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[120]. 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.

116 Pappas C. (2014) "8 Top Tips to Create an Effective Social Learning Strategy", published in eLearning Industry on 28 July 2014, available at: https://elearningindustry.com/8-top-tips-create-effective-social-learning-strategy
117 Fosway Group (2017) "Digital Learning Realities 2017: Part 1 -Organisation, Headcount, Budget and Investment", in association with learning technologies, May 2017
118 Downes S. (2016) "Personal and Personalized Learning", 17 February 2016, available at: https://www.downes.ca/cgi-bin/page.cgi?post=65065
119 *Ibid*.
120 *Ibid*.

4. STATE-OF-PLAY ANALYSIS

The current chapter presents a state-of-play analysis with regard to the key players in AMT education & 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 & training in Europe.

4.1. Key players in AMT education & 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 & 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[121]. 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.

4.1.1. 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 competences (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[122]. 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[123].

In order to analyse the quality of the Manufacturing Engineering offer in Europe, we used the **QS World University Rankings by Subject 2018[124]** (the overall ranking is based on four

121 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
122 https://www.topuniversities.com/courses/engineering-manufacturing-production/grad/guide#tab=0
123 *Ibid*.
124 https://www.topuniversities.com/subject-rankings/2018

indicators, namely academic reputation, employer reputation, citations per paper and h-index citations[125]). 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 Kingdom[126]). The majority of universities in this top 10 come from the United States[127], and one university is located in Japan[128]. 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[129] 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 4-1.

125 https://www.topuniversities.com/university-rankings/university-subject-rankings/2015/materials-sciences
126 Those include University of Cambridge, University of Oxford and Imperial College London.
127 Those include Massachusetts Institute of Technology (MIT), Stanford University, Harvard University, University of California Berkeley (UCB), University of Michigan and Georgia Institute of Technology.
128 Namely the University of Tokyo
129 https://www.timeshighereducation.com/world-university-rankings/2018/subject-ranking/engineering-and-IT

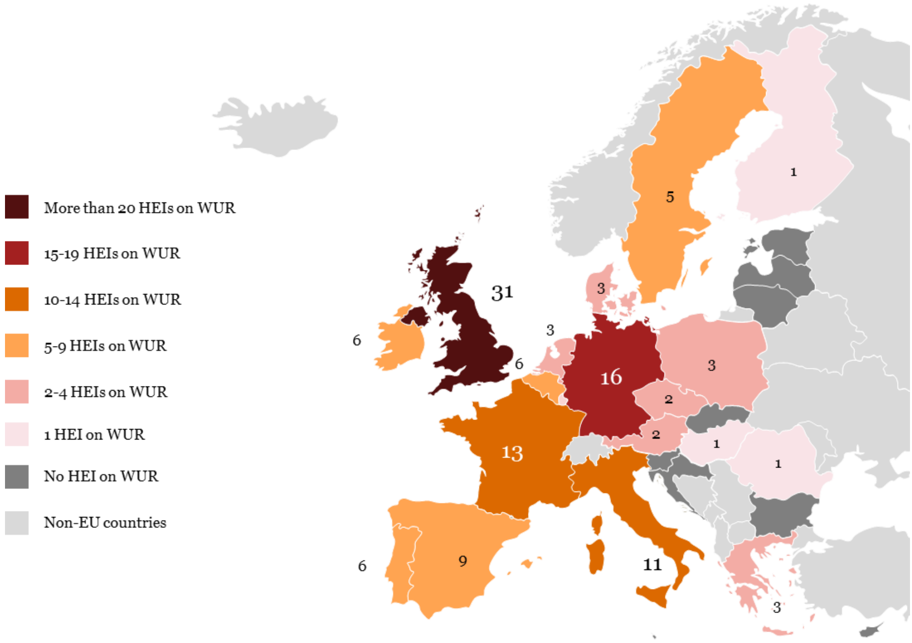


Figure 4-1: Overview of European HEIs within Manufacturing and Mechanical Engineering[130] (the list is not exhaustive)

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.

130 Based on the data from the World University Rankings, available at: 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

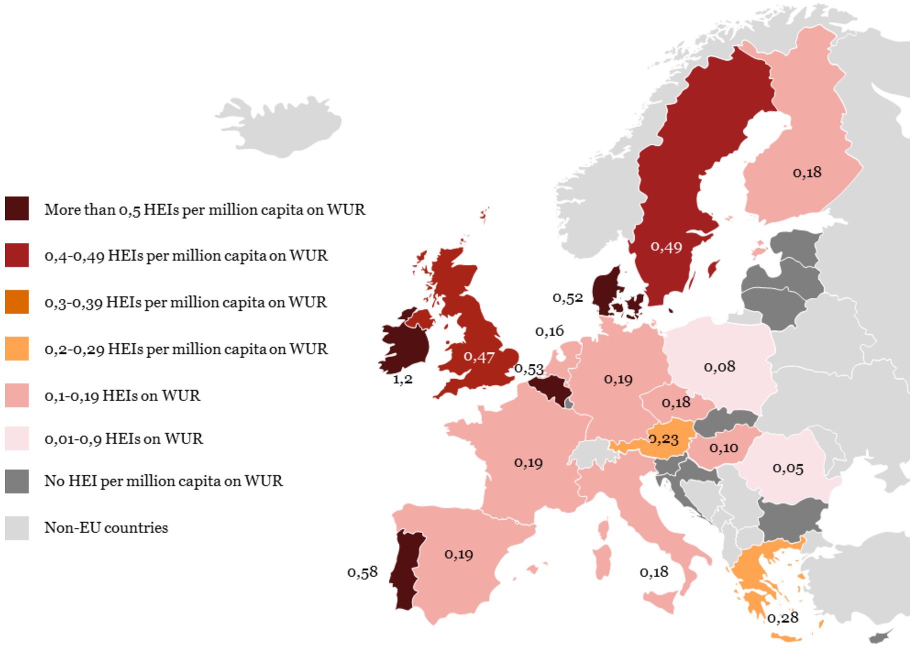


Figure 4-2: Overview of European HEIs per million capita within Manufacturing and Mechanical Engineering[131,132] (the list is not exhaustive)

Figure 4-2 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 suggest complementing the results of the abovementioned analysis with an alternative approach. The latter implies a broad stakeholder consultation, complemented 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 & training in KETs and AMT. This exercise represents work in progress and will continue in the second phase of the current initiative.

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*[133], *FindAPhD*[134] and the bachelors, masters and PhD portal *Bachelors portal*, *Masters portal* and PhD portal provided by Study Portal[135]. These three Member States (namely Finland, United Kingdom and Lithuania) were chosen in an arbitrary way, based on the availability of

131 Based on the data from the World University Rankings, available at: 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
132 Population data from Eurostat. Note that for Poland population data was only available for 2017Q4
133 Global database of 4,820 HEIs, https://www.topuniversities.com/universities
134 Approximately 4,000 PhDs in the selected countries, https://www.findaphd.com/
135 Global database of 79,793 bachelors, 59,793 masters and 4,018 PhD’s, https://www.studyportals.com/press-releases/about-studyportals-general-information/

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[136], 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[137]. The Bachelor programmes offer a fairly high level of specialisation, with programmes 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 text box below offers some more illustrative examples of relevant HEIs in Europe, collected though expert workshops.

136 https://www.port.ac.uk/study/courses/msc-advanced-manufacturing-technology
137 https://www.vgtu.lt/studies/study-programmes/undergraduate-studies/294829

Text box 4-1: Illustrative examples of AMT-related educational offer in Europe[138]

Initiative name: Aalto Design Factory[139]

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[140]

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[141] 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[142].

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

138 Based on expert workshops

139 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

140 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

141 https://www.franka.de/panda

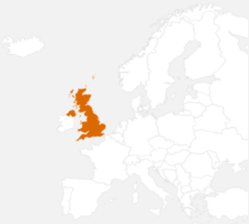
142 http://www.dw.com/en/everyman-robot-panda-wins-german-presidents-future-prize/a-41591774

Initiative name: The AMRC Training Centre[143]

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[144]

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, 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.

143 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

144 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

4.1.2. Vocational Education and Training

VET is emphasised to be key in bridging the gap between skills supply and demand[145]. 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[146].

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[147]. 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)[148]. 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, industrial operator, industry technician, plastics maker, process operator and industrial technician[149].

VET is also provided to adults to meet demand for new skills[150]. The programmes primarily provide sector and occupancy oriented skills and competences. There are more than 3,000 courses available, with a selection relevant to AMT such as robotics and 3D production[151]. 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[152]. 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[153].

145 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

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

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

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

149 Uddannelses Guiden, https://www.ug.dk/uddannelser/erhvervsuddannelser/teknologibyggeriogtransport

150 Danish Ministry of Education, http://eng.uvm.dk/adult-education-and-continuing-training/adult-vocational-training

151 https://www.efteruddannelse.dk/

152 http://www.themanufacturinginstitute.org/Skills-Certification/Certifications/NAM-Endorsed-Certifications.aspx

153 http://www.ecp2.eu/

In the context of this initiative, we aim at organising a dedicated expert workshop to collect good practice examples in the field of AMT-related VET in Europe. The workshop is scheduled for 13 December 2018 and it will be held in Brussels.

4.1.3. 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 and safety, as AM requires strict security procedures and safety measures[154].

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 informal knowledge-intensive activities as a way of training rather than engaging in formal education[155].

Text box 4-2: Illustrative example of AMT-related on-the-job training offer in Europe[156]

Festo Didactic (Germany, with facilities also in multiple other countries)[157]

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[158].

It has a broad Industry 4.0 portfolio that among others include[159]:

- 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

154 Based on expert interviews
155 EU15 Ltd et al. (2015) "European-wide e-Learning Recognition Review Report", Erasmus+ project nr. 2014-1-UK01-KA202-001610 (SMEELEARN project)
156 Based on expert workshops
157 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
158 https://www.festo-didactic.com/int-en/company/?fbid=aW50LmVuLjU1Ny4xNy4xMC4zNDQ0LjQxNDE
159 https://www.festo-didactic.com/int-en/training-and-consulting/i4.0-training-portfolio/?fbid=aW50LmVuLjU1Ny4xNy4xMC44MTUwLjQ0ODI

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.

4.1.4. 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[160]. The main purpose of learning factories is "learning" in a "factory" environment[161]. This typically refers to the academic education of students and further education of industrial employers[162]; 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 setting.

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[163]. 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[164]:

- 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);

160 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

161 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

162 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.

163 *Ibid.*

164 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

- 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[165]:

- 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);
- KTH XPRES Lab (Sweden).

Learning factories for energy and resource efficiency[166]:

- 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[167].

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

165 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

166 *Ibid*.

167 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

verified the TF potential to bring together the manufacturing learning and working environments[168].

4.2. Overview of relevant initiatives

Based on extensive desk-research and stakeholder consultation, we have developed a sample of policy initiatives aiming at strengthening education & 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.

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. 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**.

4.2.1. National and subnational policy initiatives

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.

168 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

TABLE 4-1 provides an overview of the identified policy initiatives at the national and subnational levels for the EU Member States. Per initiative, we indicate the initiating country, title, type, coordinating organisation, coverage, objective, target group and duration. In addition, the information on the results and evaluation is added whenever available.

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.

TABLE 4-1, 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. The project team will continue exploring the relevant policy landscape during the second phase of the initiative, especially based on stakeholder inputs during future workshops and interview rounds. As a result, Table 4-1 should be considered work in progress.

Our analysis suggests that there are only a few national and subnational policy initiatives explicitly focussing on education & 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[169]. 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[170] and the activities within the Slovenian Smart Specialisation Strategy (S4)[171] 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 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.

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

TABLE 4-1: Overview of identified initiatives

Nr	Country	Title	Type	Coordinator	Coverage	Objectives	Target group	Duration	Evaluation/ Results
1	Czech Republic	**National Centre for Industry 4.0**[172]	Training, promotion	National Centre for Industry 4.0	National (Czech Republic)	To support education and teaching in the area of Industry 4.0	SMEs in Czech Republic	Initiated 2017	No information was found
2	Denmark	**MADE – Manufacturing Academy of Denmark**[173,174]	Training, promotion, funding	MADE – Manufacturing Academy of Denmark	National (Denmark)	MADE's primary goal is to ensure that Denmark has a highly productive world-class advanced manufacturing industry. Herein, to optimise education to support manufacturing	Danish manufacturing SMEs and larger companies, stakeholders from research and academia	Initiated 2014. Funding from the Innovation Fund for 5 years	48 PhDs included by 2017[175]
3	France	**Industrie du Futur**[176]	Funding, training	Alliance Industrie du Futur	National (France)	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	No information was found
4	France	**Osons I'industrie**[177]	Promotion	Alliance Industrie du Futur	National (France)	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	No information was found	No information was found

172 https://www.ncp40.eu/predstaveni
173 http://www.made.dk/om-made/
174 European Commission (2017), "Denmark: Manufacturing Academy of Denmark (MADE)"
175 Innovationsfonden (2017), "Midtvejsevaluering af MADE"
176 https://ec.europa.eu/futurium/en/system/files/ged/fr_country_analysis.pdf
177 http://www.industrie-dufutur.org/osons-lindustrie/

Nr	Country	Title	Type	Coordinator	Coverage	Objectives	Target group	Duration	Evaluation/ Results
5	France	**Grande École de Numérique**[178, 179,180]	Promotion, quality standards	Ministère de l'Economie et des Finances	National (France)	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	Germany	**Plattform Industrie 4.0 – Work, education and training**[181]	Recommendations	Federal Ministry for Economic Affairs and Energy and Federal Ministry of Education and Research	National (Germany)	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[182]	Published policy recommendations, business recommendations and operational best practice
7	Germany	**Future Work Lab**[183]	Training	Fraunhofer-Gesellschaft	National (Germany)	Ensuring that the manufacturing workforce is fit for the future of work	Managers, experts and operational staff in manufacturing companies	Initiated 2017	No information was found
8	Germany	**Learning factories 4.0**[184,185]	Training	Allianz Industrie 4.0 Baden-Württemberg	Regional (Baden-Württemberg)	The aim of the training factories is to prepare specialists and junior staff for the requirements of digitisation	Employers and employees in manufacturing	No information was found	No information was found

178 https://www.grandeecolenumerique.fr/
179 https://www.economie.gouv.fr/files/files/PDF/DP-GEN160202.pdf
180 Grande École de Numérique, Chiffres Clés 2017, https://www.grandeecolenumerique.fr/wp-content/uploads/2018/06/ChiffresCles2017_GEN_WEBVF.pdf
181 https://www.plattform-i40.de/I40/Redaktion/EN/Standardartikel/Working-Groups/working-group-05.html
182 https://www.plattform-i40.de/I40/Navigation/EN/ThePlatform/PlattformIndustrie40/plattform-industrie-40.html
183 https://futureworklab.de/en.html
184 https://www.i40-bw.de/de/lernfabriken-4-0/
185 https://wm.baden-wuerttemberg.de/de/innovation/schluesseltechnologien/industrie-40/lernfabrik-40/

Nr	Country	Title	Type	Coordinator	Coverage	Objectives	Target group	Duration	Evaluation/ Results
9	Hungary	**IPAR 4.0 National Technology Platform**[186]	Promotion	The Hungarian Academy of Science Institute for Computer Science and Control and the Ministry for national Economy	National (Hungary)	The objective is to find solutions and formulate recommendations to provide education, human resources and labour market strategies	Policy makers	Initiated 2014	No information was found
10	Italy	**Industria 4.0**[187]	Promotion, funding, training	Ministry of Economic Development	National (Italy)	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	Expected results: 200.000 academic students and 3.000 managers qualified on I4.0 topics. +100% attendance at VET on I4.0 topics. Approx. 1.400 industrial PhDs focussed on I4.0 topics.
11	Latvia	**National Industrial Policy Guidelines 2014-2020**[188]	Promotion	The Latvian Ministry of Economy	National (Latvia)	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	No information was found

186 MTA Sztaki (2017), "Az IPAR 4.0 Nemzeti Technológiai Platform – Kérdoív Projekt"
187 European Commission (2017), "Italy: Industria 4.0"
188 European Commission (2018), "Latvia: National Industrial Policy Guidelines 2014-2020"

Nr	Country	Title	Type	Coordinator	Coverage	Objectives	Target group	Duration	Evaluation/ Results
12	Netherlands	**Smart Industry**[189]	Promotion	Smart Industry	National (the Netherlands)	Promote the perspective of employee skills as critical success factors and promotion of lifelong learning in industry production.	Employers	2014-2021	No information was found
13	Netherlands	**Fieldlab**[190]	Training, certification	Smart Industry	National (the Netherlands)	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	No information was found
14	Portugal	**Pense Indústria – Nova Geração**[191]	Promotion	Centimfe – Centro Tecnológico da Indústria de Moldes, Ferramentas Especiais e Plásticos	National (Portugal)	To promote a new image of industry to young people	Students in elementary and secondary education	No information was found	No information was found
15	Portugal	**Industria 4.0**[192,193]	Promotion, Quality standards, funding	COTEC Portugal	National (Portugal)	Strengthen Portuguese industry with one main pillar being education and skills	Students in all education levels, employers, industrial stakeholders	Initiated 2016	No information was found
16	Slovakia	**Smart industry**[194]	Awareness-raising	Ministry of Economy	National (Slovakia)	Identifying the future needs of the labour market and guiding education and skills-development in that direction	Policy makers	Initiated 2016	No information was found

189 http://smartindustry.nl/wp-content/uploads/2017/07/smart-industry-actieagenda-lr.pdf
190 https://www.smartindustry.nl/wp-content/uploads/2018/03/Fieldlabs-poster-EN.pdf
191 http://www.centimfe.com/index.php/pt/servicos-2/formacao/pense-industria-nova-geracao
192 https://www.industria4-0.cotec.pt/en/about/
193 https://www.industria4-0.cotec.pt/en/industry-4-0-program/action-plan/
194 European Commission (2018), “Slovakia: Smart Industry”

Nr	Country	Title	Type	Coordinator	Coverage	Objectives	Target group	Duration	Evaluation/ Results
17	Sweden	**Graduate School Produktion 2030**[195,196]	Quality standards, promotion, funding	Produktion 2030	National (Sweden)	The aim is to increase competitiveness in Swedish manufacturing industry, through co-operation between industry, academia and research institutes. Ensuring strong collaboration between industry and academia in higher education	PhD students, Postgraduates, academics and industrial stakeholders	Initiated 2014	30 higher education courses within product and production development
18	United Kingdom	**Employer Ownership of Skills**[197,198]	Funding	UK Commission for Employment and Skills	National (United Kingdom)	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[199]

195 https://www.p2030graduateschool.se/graduate-school/about-the-graduate-school-31106479
196 https://produktion2030.se/wp-content/uploads/prod2030_ny_Agenda_210x230_20181.pdf
197 UKCES (2011), Employer Ownership of Skills
198 UKCES (2012), Employer Ownership of Skills Pilot – Round 2 Prospectus
199 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	United Kingdom	**Skills for innovation in manufacturing** [200]	Funding	UK Commission for Employment and Skills	National (United Kingdom)	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 the need to manage innovation, demonstrating different approaches to tackling innovation management and supporting companies through making changes in their work practices[201]

200 UKCES (2015), UK Futures Programme Competition brief: Skills for Innovation in Manufacturing
201 UKCES (2016), Evaluation of UK Futures Programme – Final Report on Productivity Challenge 4: Skill for Innovation in Manufacturing

4.2.2. 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. Amongst these actions the following two programmes stand out as particularly relevant for this analysis:

- **Blueprint for Sectoral Cooperation on Skills – Additive manufacturing**[202]: a framework for cooperation between key stakeholders to address short and medium-term skills shortages in additive manufacturing, launching in 2018.
- **Blueprint for Sectoral Cooperation on Skills – Automotive**[203]: 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[204] (the list is of illustrative nature and should not be considered as exhaustive).

- **CompoHUB[205] (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[206] (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.
- **Automation, technology transfer and managerial practices for the growth of SMEs, a better employability and the promotion of the entrepreneurship (AuToMa)[207,208] (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.

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202 European Commission (2018) "A Blueprint for Sectoral Cooperation on Skills Additive manufacturing"
203 European Commission (2017) "Blueprint for Sectoral Cooperation on Skills Automotive"
204 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)
205 http://www.compohub.eu/
206 https://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/2015-1-ES01-KA202-016250
207 http://www.automa-project.eu/article/details/3
208 https://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/2016-1-IT01-KA202-005599

- **Robotics automation careers in engineering for the 21 century (RACE21)[209] (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[210] (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)[211] (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)[212] (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[213] (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.

Another important group of Erasmus+ part-funded initiatives is the **Sector Skills Alliances** and **Knowledge Alliances**. The alliances aim at reducing the skills gap in specific sectors by working in transnational cooperation. To identify relevant initiatives, we have reviewed the relevant projects for both Sectoral Skills Alliances and Knowledge Alliances for 2015-2018[214,215,216,217,218,219,220,221] (the list is of illustrative nature and should not be considered as exhaustive):

209 http://race21.epa.edu.pt/
210 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
211 http://www.mechmate.eu/
212 http://www.digit-t.eu/
213 https://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/2017-1-CZ01-KA204-035528
214 https://eacea.ec.europa.eu/sites/eacea-site/files/essa_selection_results_2015_en.pdf
215 https://eacea.ec.europa.eu/sites/eacea-site/files/publication_ssa_selection_results_2016.pdf
216 https://eacea.ec.europa.eu/sites/eacea-site/files/selection_results_for_the_web_0.pdf
217 https://eacea.ec.europa.eu/sites/eacea-site/files/sector_skills_alliances_2018-list_of_selected_projects_for_web.pdf
218 https://eacea.ec.europa.eu/sites/eacea-site/files/v3-publication_ka_selection_results_2016-30-09-2016.pdf
219 https://eacea.ec.europa.eu/sites/eacea-site/files/updated_31oct2017-publication_ka_selection_results_2017.pdf
220 https://eacea.ec.europa.eu/sites/eacea-site/files/ka_selection_results_2018.pdf
221 https://eacea.ec.europa.eu/sites/eacea-site/files/knowledge_alliances_selection_results_2015-12-02.pdf

- **Sector Skills Alliance for advanced manufacturing in the transport sector (Skill Man)[222] (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)[223] (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.

- **3D Printing Skills for Manufacturing (3DPrism)[224] (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)[225] (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[226] (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)[227] (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)[228]:** 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)[229] (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.

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222 http://skillman.eu/
223 http://www.metalsalliance.eu/objectives/
224 https://3dprism.eu/
225 https://www.gzs.si/skill-me/vsebina/O-nas
226 http://makeitproject.eu/project.html
227 http://change4industry.eu/en/pages/home/about-project.html
228 http://www.memevet.eu/
229 http://cllaimprojectam.eu/index.html

- **Development and Research on Innovative Vocational Education Skills (DRIVES)[230] (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)[231] (launched in 2018):** The OD&M Knowledge Alliance aims to achieve in-depth understanding of the OD&M paradigm in business models and production processes, as well as understanding which new knowledge, competences and skills are needed to boost it at meaningful scale.

- **Knowledge Alliance for AdDitive Manufacturing between Industry and univeRsitiEs (ADMIRE)[232] (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)[233] (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[234]. 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**[235,236,237], will be 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**[238] and **Digitalisation and the Future of Work**[239].

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**[240] and the initiatives under the European Commission's **Smart Specialisation Platform for Industrial Modernisation** (S3P-Industry)[241].

230 http://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/443fbc62-25f7-4121-94c4-3c65ff67b258
231 https://odmplatform.eu/
232 http://admireproject.eu/goal.html
233 http://www.smeart.eu/
234 https://eacea.ec.europa.eu/erasmus-plus/actions/key-action-1-learning-mobility-individuals
235 https://eit.europa.eu/eit-community/eit-glance
236 https://eit.europa.eu/collaborate/2018-call-for-proposals
237 https://eit.europa.eu/activities/education
238 http://www.cedefop.europa.eu/en/events-and-projects/projects/forecasting-skill-demand-and-supply
239 http://www.cedefop.europa.eu/en/events-and-projects/projects/digitalisation-and-future-work
240 https://ec.europa.eu/commission/news/new-industrial-policy-strategy-2017-sep-18_en
241 http://s3platform.jrc.ec.europa.eu/industrial-modernisation

With regard to international initiatives, a prominent example refers to the **CDIO initiative**[242], 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 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[243].

4.3. Overview of key publications

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

4.3.1. 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 2013), 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 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 the key insights from the latest publications. Stakeholders are invited to indicate other relevant publications that need to be included in this list.

Table 4-2 provides an overview of the screening results. The selected publications are presented in the chronological order (starting from the most recent one). *Annex D* (section D.1) of the report provides an overview of the abstracts per publication. Most of the identified scientific literature concerns education and training in Advanced Manufacturing in general. However, some publications put emphasis specifically on the automotive sector and on the additive manufacturing technology.

A prominent pattern in the identified literature refers to **the need for close cooperation between education & training providers and industry**[244,245]. 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[246,247], apprenticeships, web-based virtual learning, gamification and expert centres.

242 http://www.cdio.org/about

243 *Ibid*.

244 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

245 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

246 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

247 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 4-2: Overview of key scientific publications

Nr	Publication
1.	Paravizo, E., Chaim, O. C., Braatz, D., Muschard, B., Rozenfeld, H. (2018) "**Exploring gamification to support manufacturing education on industry 4.0 as an enabler for innovation and sustainability**", Procedia Manufacturing, 21, pp. 438-445
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.	Despeisse, M., & Minshall, T. (2017) "**Skills and Education for Additive Manufacturing: A Review of Emerging Issues**", in IFIP International Conference on Advances in Production Management Systems (pp. 289-297). Springer, Cham.
4.	Gorecky, D., Khamis, M., Mura, K. (2017) "**Introduction and establishment of virtual training in the factory of the future**", International Journal of Computer Integrated Manufacturing, 30(1), pp. 182-190
5.	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.
6.	Mirkouei, A., Bhinge, R., McCoy, C., Haapala, K. R., Dornfeld, D. A. (2016) "**A Pedagogical Module Framework to improve Scaffolded Active Learning in Manufacturing Engineering Education**", Procedia Manufacturing, 5, pp.1128-1142
7.	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
8.	Kolmos A., Hadgraft R., Holgaard J. E. (2016) "**Response strategies for curriculum change in engineering**", International Journal of Technology and Design Education, 26(3), pp. 391-411
9.	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
10.	Choi, S., Jung, K., & Noh, S. D. (2015) "**Virtual reality applications in manufacturing industries: Past research, present findings, and future directions**", Concurrent Engineering, 23(1), 40-63.
11.	Huang, Y. and Leu, M.C. (2014), "**Frontiers of Additive Manufacturing Research and Education**", University of Florida, Report of NSF Additive Manufacturing Workshop
12.	Lewis, P. (2014) "**The over-training of apprentices by employers in advanced manufacturing: a theoretical and policy analysis**", Human Resource Management Journal, 24(4), pp. 496-513
13.	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
14.	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.
15.	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
16.	Wong, D. S. K., Zaw, H. M., Tao, Z. J. (2014) "**Additive manufacturing teaching factory: driving applied learning to industry solutions**", Virtual and Physical Prototyping, 9:4, pp. 205-212
17.	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
18.	Mavrikios, D., Papakostas, N., Mourtzis, C. (2013) "**On industrial learning and training for the factories of the future: a conceptual, cognitive and technology framework**", Journal of Intelligent Manufacturing, 24(3), pp. 473-485
19.	Chryssolouris, G., Mavrikios, D., Mourtzis, D. (2013) "**Manufacturing systems: skills & competencies for the future**", Procedia CIRP, 7, pp. 17-24
20.	Jovanovic, V., Hartman, N.W. (2013) "**Web-based virtual learning for digital manufacturing fundamentals for automotive workforce training**", International Journal of Continuing Engineering Education and Life-Long Learning, 23, pp.300–310
21.	Gorecky, D., Mura, K., Arlt, F. (2013) "**A Vision on Training and Knowledge Sharing Applications in Future Factories**", IFAC Proceedings Volumes, 46(15), pp. 90-97

4.3.2. 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 2013), 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 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. Stakeholders are invited to indicate other relevant publications that need to be included in this list.

Table 4-3 provides an overview of results. The selected publications are presented in the chronological order (starting from the most recent one). *Annex D* (section D.2) of the report provides an overview of the abstracts per publication.

TABLE 4-3: Overview of key business and policy publications

Nr	Publication
1.	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
2.	Graham R. (2018) "**The global state of the art in engineering education**", MIT School of Engineering, March 2018
3.	Pei, E., Monzón, M., Bernard, A. (2018) "**Additive Manufacturing - Developments in Training and Education**", Springer
4.	Magid, E., Sabirova, L., Tsoy, T. (2017) "**Towards Effective Interactive Teaching and Learning Strategies in Robotics Education**", 10th International Conference on Developments in eSystems Engineering (DeSG)
5.	Dumitrescu, E., Feige, E., Lacopeta, C., Radermacher, A. (2017) "**To make a transformation succeed, invest in capability building**", McKinsey & Company
6.	Despeisse, M., Minshall, T. (2017) "**Skills and Education for Additive Manufacturing: A Review of Emerging Issues**", IFIP Advances in Information and Communication Technology
7.	Swearer, R. (2016) "**Why Manufacturing Education Needs to Advance, just like you have**", Industry Weekly, published on Aug. 23rd 2018
8.	PwC, Manufacturing Institute (2016) "**Upskilling manufacturing: How Technology is disrupting America's industrial labor force**", PwC
9.	VDI (2015) "**A Discussion of Qualifications and Skills in the Factory of the Future: A German and American Perspective**", VDI
10.	Djuric, A., Jovanovic, V., Goris, T. (2015) "**Preparing students for the advanced manufacturing environment through robotics, mechatronics and automation training**", ASEE Annual Conference and Exposition, Conference Proceedings. 122.
Other relevant publications	
11.	Barber, M., Hill, P. (2014) "**Preparing for a Renaissance in Assessment**", Pearson
12.	Paterson J. (2018) "**Google's IT certification heads for college curriculum**", published in EducationDive on 27 September 2018, available at: https://www.educationdive.com/news/googles-it-certification-heads-for-college-curriculum/533343/
13.	Fain P. (2018) "**Google curriculum, college credit**", published in Inside Higher ED on 26 September 2018, available at: https://www.insidehighered.com/digital-learning/article/2018/09/26/growing-number-colleges-partner-google-offer-credit-its-new-it
	WEF (2018) "**The Future of Jobs Report 2018**", published in 17 September 2018, available at: https://www.weforum.org/reports/the-future-of-jobs-report-2018
14.	Virgo P. (2018) "**Education and training to help build the future, not just preserve the past**", published in ComputerWeekly on 5 September 2018, available at: https://www.computerweekly.com/blog/When-IT-Meets-Politics/Education-and-training-to-help-build-the-future-not-just-preserve-the-past
15.	Oblinger D. (2018) "**Smart Machines and Human Expertise: Challenges for Higher Education**", pulished in Educause review on 27 August 2018, available at: https://er.educause.edu/articles/2018/8/smart-machines-and-human-expertise-challenges-for-higher-education
16.	Phelps J. (2018) "**Scenarios, Pathways, and the Future-Ready Workforce**", pulished in Educause review on 27 August 2018, available at: https://er.educause.edu/articles/2018/8/scenarios-pathways-and-the-future-ready-workforce
17.	Council on Foreign Relations (2018) "**The Work Ahead: Machines, Skills and U.S. Leadership in the Twenty-First Century**", Independent task Force Report nr. 76, available at: https://cfrd8-files.cfr.org/sites/default/files/The_Work_Ahead_CFR_Task_Force_Report.pdf
18.	Luckin R. (2018) "**Machine Learning and Human Intelligence**", UCL IOE Press
19.	Moghaddam Y. et al. (2018) "**T-shaped professionals: Adaptive innovators**", Service Systems and Innovations in Business and Society Collection, Business Expert Press
20.	Winick E. (2018) "**Every study we could find on what automation will do to jobs, in one chart**", published in MIT Technology Review on 25 January 2018, available at: https://www.technologyreview.com/s/610005/every-study-we-could-find-on-what-automation-will-do-to-jobs-in-one-chart/

Nr	Publication
21.	Davies S. (2017) "**End of year report: Exploring the need for education in additive manufacturing**", published in tct Magazine on 18 September 2017, available at: https://www.tctmagazine.com/3d-printing-news/end-of-year-report-education-additive-manufacturing/
22.	McKinsey&Company (2017) "**The great re-make: Manufacturing for modern times**", June 2017
23.	PwC (2017) "**Key lessons from national industry 4.0 policy initiatives in Europe**", a report for the European Commission in the context of the Digital Transformation Monitor, May 2017
24.	Swearer R. (2016) "**Why Manufacturing Education Needs to Advance, Just Like You Have**", published in IndustryWeek on 23 August 2016, available at: https://www.industryweek.com/education-training/why-manufacturing-education-needs-advance-just-you-have
25.	UK Commission for Employment and Skills (2015) "**Sector insights: skills and performance challenges in the advanced manufacturing sector**", Evidence Report 93, June 2015
26.	Campbell K. et al. (2014) "**Manufacturing workforce development playbook: Preparing for the manufacturing renaissance in America**", Summit Media Group
27.	EFFRA (2013) "**Multi-annual roadmap for the contractual PPP under Horizon 2020**", a report prepared for the European Commission
28.	Forfás (2013) "**Future Skills Requirements of the Manufacturing Sector to 2020**", Expert group on Future Skills Needs, February 2013
29.	Davenport, T. H. (2013) "**The Future of the Manufacturing Workforce**", Manpower

4.4. 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 & training in AMT-related domains. These curricula have been identified **based on the QS World University Rankings by Subject 2018**[248] (the overall ranking is based on four indicators, namely academic reputation, employer reputation, citations per paper and h-index citations[249]). 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 4-4 provides an overview of the selected programmes and corresponding curricula.

TABLE 4-4: 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

248 https://www.topuniversities.com/subject-rankings/2018
249 https://www.topuniversities.com/university-rankings/university-subject-rankings/2015/materials-sciences

Nr	Education provider	Country	Programme title
8.	RWTH Aachen University	Germany	MSc. Materials and Process Engineering Specialization
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 E* 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 & training principles in practice and (whenever relevant) provide the corresponding impact assessment.

4.5. 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 & 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 & 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 & training systems

Educational system has been historically slow to adopt innovations for many reasons[250]. 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[251]. Innovation is difficult to spread across the education & training system because it disrupts the established routine[252]. 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[253].

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

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250 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.

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

252 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.

253 *Ibid*.

- **Teachers/trainers and administrators are often cautious about top-down induced change** and have limited tolerance for the uncertainty that any major innovation causes[254]. 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[255].

- **Innovation in education & 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 & 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 & 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[256].

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 physical access to the machinery. Adding to the challenges, machines quickly become outdated in such a fast evolving-market. Finally,

254 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.
255 *Ibid*.
256 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.

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[257].

Solutions to stimulate change in education & training systems

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

- **Organising education & training around learners rather than teachers/trainers**: developing education & 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 & 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[258]. In the context of the current initiative, we aim to further tailor these solutions to the needs of the AMT domain. The resulting implications for teacher training have also been addressed in more detail in section 3.2.5 of this report.

257 Based on expert interviews
258 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

5. Draft proposal for curriculum guidelines

The current initiative aims to produce curriculum guidelines for Europe's education & training organisations, highlighting the key points of attention and good practice examples, when it comes to aligning their approach with the 21st Century needs. The guidelines will be developed based on the extensive state-of-play analysis and active stakeholder contribution. The current chapter presents systemised initial inputs for the draft curriculum guidelines.

5.1. Key principles for developing curriculum guidelines

The curriculum guidelines need to be 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 (which forms the core of our approach).
- **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.
- **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 such as KETs, 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

The aim is to follow a holistic approach covering a broad spectrum of dimensions relevant to curriculum design and implementation. Specifically, the following eight dimensions will be considered by the analytical framework (as presented in Figure 5-1):

(1) Strategy;
(2) Collaboration;
(3) Content;
(4) Learning environment;
(5) Delivery mechanisms;
(6) Assessment;
(7) Recognition;
(8) Quality.

FIGURE 5-1: Curriculum Guidelines framework

Strategy 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 will be 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 refers to connecting individuals and institutions by facilitating the exchange of practices and resources with a view to improve the educational offer. Special attention will be paid to practices that move beyond the typical institutional collaboration patterns and engaging individuals and communities. We also aim 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.

Content dimension refers to the nature of educational content and includes specific principles related to the actual content of the curricula (syllabus design principles).

Learning environment includes types of environment that is created during the programme, e.g. stimulating multidisciplinary orientation, design thinking, team spirit, collective problem-solving, risk-taking behaviour, experimental approaches etc.

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, we aim at addressing the role of technology-enabled learning, including traditional e-learning, MOOCS, SPOCs, mLearning, gaming, virtual and augmented reality, AI solutions etc.

We also aim at exploring the most appropriate forms of **assessment**, e.g. self-assessment through which students learn to monitor and evaluate their own learning (trains the ability to be reflective and self-critical); peer assessment, in which students 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, including both advantages and disadvantages.

Recognition 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, we aim at exploring appropriate formal and informal ways of recognition.

We also aim to look at the determinants of education & training **quality**: what makes students' and employers' perception different? We are specifically looking at good practice examples in quality assurance.

The inputs for each element of the curriculum guidelines framework are collected by means of targeted desk-research, and with **active stakeholder engagement** via expert workshops, online survey, as well as in-depth interviews and individual stakeholder consultations. We specifically disseminated an input form template among 54 identified experts, with a request to provide their suggestions for the specific elements of the guidelines. We are currently in the process of collecting and systemising these inputs. 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.

5.3. Zooming into each of the elements of the Curriculum Guidelines Framework

The current sub-section provides a preliminary overview of the inputs collected so far, and should be viewed as work in progress. During the second phase of this initiative, we also aim to specify the role of specific stakeholders within each of the eight domains, i.e. indicating who has to do what, as well as to add a map with timelines for the relevant actions (i.e. short-term, mid-term and long-term). The key relevant stakeholder groups include education & training providers, companies, policy makers, as well as supporting structures (e.g. industry associations, unions and worker associations etc.).

5.3.1. Strategy

Within the Strategy domain, we aim to focus specifically on the conceptual aspects of the educational offer such as[259]:

- **Assessing learners' needs:** it is important to think of each learner as an individual with a different learning style and motivation. It is not enough to provide learners with the time and access to content, there is also a need to provide a conducive environment for continuous learning. Doing so has many implications for the method of pedagogy and the changing roles of the employers during the learning process[260]. Designing a conducive environment for learners engaged in continuous learning implies the following considerations:
  - learning/training is no longer seen as a one-off event but as a long-term process where each individual learns at their own pace and gains experience over time[261];
  - the individual receives not just technical and monetary support, but also support for the social and emotional aspects of learning[262];
  - learning is deeply embedded in the way of working such that informal and blended learning are not only possible but also highly effective[263];
  - individuals are able to gain not just certification but also recognition within their communities of practice for their experience and expertise[264];
  - learning/training of the individual is not only beneficial for increasing productivity of the company, but also relevant for the lifetime career trajectory of the individual[265].
- **Developing curriculum goals:** educational institutes and training providers need to target several goals to be achieved with the curricula they develop – both in the short-term and the long-term[266]. In the short-term, curricula may focus on adopting new ways of working to achieve increased productivity and efficiency, such as achieving high quality high volume output with minimum errors and accidents, or using data to enhance

259 PwC analysis incorporating multiple expert sources
260 https://faculty.londondeanery.ac.uk/other-resources/files/BJHM_348_351_CTME_needs.pdf
261 https://core.ac.uk/download/pdf/82367162.pdf
262 https://www.newvisions.org/blog/entry/social-emotional-learning-and-adult-learning-connecting-the-dots
263 http://www.cogprints.org/637/1/LearnbyDoing_Schank.html
264 https://pdfs.semanticscholar.org/11c7/75f8a059d6100ad7f5e499ab1300e4c1747f.pdf
265 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/590419/skills-lifelong-learning-learning-across-the-lifetime.pdf
266 https://www.cna.nl.ca/About/pdfs/policies-and-procedures/Human%20Resources/Continuous%20Learning/3Documents/CL%20Handbook.pdf

strategic, tactical and innovative decision-making. Long-term and broader-scale goals may also be considered, such as cultivating and maintaining culture of learning and a sense of meaningful purpose, or developing high sensitivity to diversity, culture and ethics in business. Ideally, education and training need to combine both long-term and short-term goals in every offering, so as to diffuse these values into the workforce at every level.

- **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[267]. 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 and companies. Since no one metric can comprehensively signal successful outcomes, a holistic combination of metrics is highly recommended, 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.

5.3.2. Collaboration

Collaboration refers to connecting individuals and institutions by facilitating the exchange of practices and resources with a view to improve the educational offer. Special emphasis needs to be put on the following aspects:

- **New collaboration patterns among institutions:** moving towards a paradigm of lifelong learning, educational institutions also need to evolve and occupy new roles in the ecosystem. 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[268]. 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[269]. 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[270]).

267 https://core.ac.uk/download/pdf/4152582.pdf
268 https://evolllution.com/managing-institution/internal_service_partnerships/benefits-and-challenges-in-partnerships-between-continuing-education-and-faculties/
269 https://trainingindustry.com/articles/workforce-development/partnerships-with-educational-institutions-help-to-fill-skill-gaps-and-create-confident-employees/
270 https://fitech.io/fitech/

- **Individual or community engagement:** adult learners typically have different needs, motivations and learning styles compared to students[271]. 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[272]. It is also necessary to acknowledge the emotional aspects of learning, which can be accommodated within a social and collaborative learning environment[273]. Contrary to traditional one-way pedagogy, it is increasingly a possibility to engage communities of practice as knowledge-sharing networks[274]. 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[275]. Thus highlighting the social and societal angle may also serve to engage and motivate a larger group of adult learners.

- **Empowering learners to collaborate with peers and organisations:** empowerment may be defined along the six dimensions of impact, self-efficacy, autonomy, involvement in decision-making, opportunities for professional growth and professional status[276]. As such, empowerment is a holistic concept that provides educational institutions and training providers many opportunities to innovate within the domain of lifelong learning. Many of these dimensions - especially impact, involvement in decision-making and professional status – are fundamentally applicable within a network or ecosystem. In other words, empowerment in learning shifts the focus from personal knowledge gain to recognition for meaningful outcomes coming from multiple stakeholders. Thus connecting learners within communities of peers and relevant organisations helps them to align their learning goals with the view to solving real world challenges. Technology (such as social networks or forums) may play a big role in connecting communities across borders and time zones[277].

5.3.3. Content

With regard to content, the following aspects need to be taken into consideration[278]:

- **Nature of educational content**: educational content to train workers in the AMT domain needs to include both technical and non-technical topics, teaching both hard and soft skills.

    - In terms of technical skillsets, 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, workers need to develop a deep sense of familiarity with AMT, and understand its benefits and limitations at an intuitive level[279].

    - Non-technical (soft) skills also need to be adequately addressed, such as the importance of both physical and mental health and safety, the link between

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271 https://www.ryerson.ca/content/dam/lt/resources/handouts/EngagingAdultLearners.pdf
272 http://northernc.on.ca/leid/docs/engagingadultlearners.pdf
273 https://www.newvisions.org/blog/entry/social-emotional-learning-and-adult-learning-connecting-the-dots
274 https://sloanreview.mit.edu/article/designing-effective-knowledge-networks/?fbclid=IwAR2AO0cgKWdKJ-GAJrDaOylwm_FVbCiGbenZVnA3_yxcJwZxjCntG-gURmU
275 https://www.wea.org.uk/sites/default/files/WEA_Impact_Report_2017_0502.pdf
276 https://www.questia.com/library/journal/1P3-1372352531/empowerment-a-method-of-motivating-adult-learners
277 https://sloanreview.mit.edu/article/designing-effective-knowledge-networks/?fbclid=IwAR2AO0cgKWdKJ-GAJrDaOylwm_FVbCiGbenZVnA3_yxcJwZxjCntG-gURmU
278 PwC analysis incorporating multiple expert sources
279 https://e-colorado.coworkforce.com/File.aspx?ID=45618

resource efficiency and sustainability, creative thinking and problem solving, how to collaborate in interdisciplinary teams and the principles of innovation, among many others[280].

- **Principles of syllabus design**: 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, define students' and teachers' roles, and manage expectations by setting clear learning outcomes[281]. 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[282,283]. 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 may be explored to diffuse the necessary knowledge to the right audience in the most effective way possible.

    - Some examples[284] 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 learning outcomes.

5.3.4. Learning environment

The learning environment refers to both the qualities of the physical space in which learning activities are situated and other intangible aspects that support and enhance the social and emotional dimensions of learning. The following considerations need to be taken into account[285]:

- **From a technical perspective, learning environments suited for AMT need to be physically capable to support experiences** that would be relevant to real-world working conditions. In other words, the learning environment itself would be visibly similar to a factory setting, featuring modern and state-of-the-art equipment[286]. Such an environment can not only support hands-on training and learning-by-doing[287], but also serve as a test-bed for new technologies or processes, or simply expose workers to new techniques and processes. These environments must 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.

280 https://www.workforcesystem.org/DocumentCenter/View/3352/Manufacturing-Soft-Skills-Standards---July-2017?bidId=
281 https://acert.hunter.cuny.edu/blog/syllabus-design/2015/07/30/
282 https://www.trainingzone.co.uk/community/blogs/markben/best-delivery-methods-for-adult-training
283 https://www.clearhorizon.com.au/all-blog-posts/adult-learning-principles-and-styles-areas-to-consider-when-delivering-training.aspx
284 https://www.trainingzone.co.uk/community/blogs/markben/best-delivery-methods-for-adult-training
285 PwC analysis incorporating multiple expert sources
286 https://www.chalmers.se/en/departments/ims/news/Pages/New-State-of-the-art-lab-at-Chalmers.aspx
287 http://www.engineersjournal.ie/2016/02/23/learning-factories-a-new-approach-to-training-in-advanced-manufacturing/

- **AMT learning environments may also 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.

- **There is a need to address intangible aspects that are required in adult learning environments**: the social and emotional dimensions[288] of learning require spaces that allow for reflection, discussing frustrations, sharing resources and help with making difficult choices. In addition to supporting the effectiveness of individual learning, such an environment would also inculcate valuable soft skills – such as social awareness, relationship skills and responsible decision-making – that are required in a dynamic work environment[289].

5.3.5. 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[290]:

- **E- and m-Learning**: with the improving economics of cloud computing, the promise of e-learning anytime anywhere is becoming a reality[291]. Moreover, cloud tools such as shared folders and collaborative document editing allow groups of students to participate and tackle assignments collectively rather than just individually. The ubiquity of smartphones have also unlocked the possibility of m-Learning[292]. However, m-Learning cannot replicate e-Learning content directly due to the nature and usage of mobile devices[293]. For example, m-learning is well-suited for bite-sized learning with practical relevance rather than longer content with more theoretical aspects[294].

- **MOOCs and SPOCs**: MOOCs are rapidly gaining popularity, especially with the growing recognition of platforms like EdX[295], Coursera[296] and FutureLearn[297]. 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 students 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

288 https://www.newvisions.org/blog/entry/social-emotional-learning-and-adult-learning-connecting-the-dots
289 https://casel.org/what-is-sel/
290 PwC analysis incorporating multiple expert sources
291 https://www.opencolleges.edu.au/informed/features/the-ten-emerging-technologies-in-education-and-how-they-are-being-used-across-the-globe/
292 https://www.opencolleges.edu.au/informed/features/the-ten-emerging-technologies-in-education-and-how-they-are-being-used-across-the-globe/
293 https://elearningindustry.com/top-5-design-considerations-for-creating-mobile-learning
294 https://www.infoprolearning.com/blog/9-guidelines-to-design-fantastic-mobile-learning-mlearning/
295 https://www.edx.org
296 https://www.coursera.org
297 https://www.futurelearn.com

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[298].

- **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[299]. 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[300]. 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[301]. 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.

- **Immersive technologies like Virtual and Augmented Reality (VR/AR)** 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[302]. 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.

298 https://trainingmag.com/trgmag-article/do's-don'ts-moocs-spocs/
299 https://www.opencolleges.edu.au/informed/features/the-ten-emerging-technologies-in-education-and-how-they-are-being-used-across-the-globe/
300 https://www.opencolleges.edu.au/informed/features/the-ten-emerging-technologies-in-education-and-how-they-are-being-used-across-the-globe/
301 https://www.opencolleges.edu.au/informed/features/6-emerging-educational-technologies-used-across-globe/
302 https://www.revinax.net/virtual-learning-and-memory/

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.

5.3.6. 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[303]:

- **Self-assessment:** it involves learners evaluating their own work and progress towards the learning objectives[304]. 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 students 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[305]. 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[306]. 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[307].

    - 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

303 PwC analysis incorporating multiple expert sources
304 https://teachingcommons.stanford.edu/resources/teaching/evaluating-students/assessing-student-learning/student-self-assessment
305 https://www.tp.edu.sg/staticfiles/TP/files/centres/pbl/pbl_kelvin_and_ho_keat.pdf
306 https://teachingcommons.stanford.edu/resources/teaching/evaluating-students/assessing-student-learning/peer-assessment
307 http://citt.ufl.edu/online-teaching-resources/assessments/peer-review-in-online-learning/

answer sheets, online quizzes with pre-defined answers or even AI-enabled personalised testing methods[308,309,310]. 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 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.
- 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.[311]. These modes of assessment are best done using a combination of human judgement and complementary data from AI analysis.

5.3.7. 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[312]. 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[313]:

- **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[314].
    - 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

308 https://teachingcommons.stanford.edu/resources/teaching/evaluating-students/creating-assignments/papers-projects-and-presentations
309 https://teachingcommons.stanford.edu/resources/teaching/evaluating-students/assessing-student-learning/automated-grading-exercises
310 https://teachingcommons.stanford.edu/resources/teaching/evaluating-students/assessing-student-learning/artificial-intelligence-assessment
311 https://www.cut-e.com/solutions/video-assessment/
312 http://uil.unesco.org/lifelong-learning/recognition-validation-accreditation
313 PwC analysis incorporating multiple expert sources
314 http://uil.unesco.org/lifelong-learning/qualification-frameworks/global-inventory-regional-and-national-qualifications-0

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 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 competences by peers or stakeholders who work with/around the individual[315]. 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[316].
  - Informal recognition can be organically identified and further enhanced in the area of communities of practice[317]. 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[318].

5.3.8. Quality

Developing clear and effective measures of educational quality is an important venue for research[319]. Quality refers to the expectations of both students and employers[320]:

- **Employer expectations for quality in professional training:** to a large extent, the quality of employees' professional training relates directly to the 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[321]. In other words, employers are looking for more than just qualifications, and focusing also on values, behaviours and skillsets[322]. Values such as integrity, accountability, continuous

315 http://www.lifelong-learning.lu/Detail/Lexique/Accueil/reconnaissance-des-acquis-d_apprentissage/en
316 https://www.techrepublic.com/article/google-apple-among-15-top-companies-where-you-can-get-hired-without-a-college-degree/
317 https://thesystemsthinker.com/communities-of-practice-learning-as-a-social-system/
318 https://www.ibm.com/developerworks/community/groups/service/html/communityview?communityUuid=ee240a4b-d911-46d3-b815-fc8a70d67b27
319 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.
320 PwC analysis incorporating multiple expert sources
321 https://learningforward.org/docs/default-source/pdf/why_pd_matters_web.pdf
322 Business Council of Australia – Being Work Ready: A Guide to What Employers Want

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.

- **Student expectations for quality in professional training**: in general, students 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, students 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[323,324]. 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 students 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.

323 https://files.eric.ed.gov/fulltext/ED503369.pdf
324 https://www.ncver.edu.au/__data/assets/file/0008/10133/learner-expectations-and-experiences-806.pdf

6. Identified challenges, mitigation measures and next steps

The current chapter addresses the identified challenges and applied mitigation measures. It also provides an overview of the next steps.

6.1. Key challenges and mitigation measures

During the implementation of the activities of the first phase of this initiative (under WP1), several challenges were encountered and had to be mitigated. These challenges and the applied mitigation measures are presented in Table 6-1.

TABLE 6-1: Encountered challenges and implemented mitigation measures for WP1

Risk	***Description***	***Mitigation measures***
Risk of a low attendance rate of the workshops	There was a risk that the workshops will not be attended by a sufficient number of experts.	In order to ensure active mobilisation of stakeholders, we aimed at active collaboration with the key pan-European networks and communities, including networks of educators and training providers (VET, HE and on-the-job training), KETs-related industry associations, networks of policy makers focussed on education and employment policies, and other supporting communities. The workshops were actively promoted among these communities; specific workshop participants were also be nominated by the coordinators of the abovementioned communities.
Risk of omitting certain relevant initiatives	A risk exists of omitting certain initiatives that prove hard to find, especially when national policy initiatives or planned policy initiatives are concerned.	The current initiative does not aim to develop a comprehensive overview of the relevant initiatives. Instead, we aimed at an overview that 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. These initiatives were identified by means of extensive desk-research and stakeholder consultation. Stakeholders are invited to submit additional examples in the course of the whole initiative.
Risk of omitting certain key stakeholder groups	The key relevant stakeholder groups include education & training providers, companies, policy makers, as well as supporting structures (e.g. industry associations, unions and worker associations etc.) and learners. There is a risk that some of the key stakeholder groups will not be engaged in the activities of	A wide stakeholder engagement strategy has been developed by the project team in order to make sure that all key stakeholder groups are included. The first step included mapping all the key stakeholder groups, which was followed by identifying the key communication channels and key messages to convey. Stakeholders are being reached by means of expert workshops, online surveys, individual consultations, and in-

Risk	***Description***	***Mitigation measures***
	this initiative.	depth interviews. For ensuring a broad stakeholder coverage, the project team closely collaborates with the coordinators of relevant established networks and communities (e.g. relevant industry associations, research networks and unions and student associations).
Absence or weakness of information sought	The information sought may be absent from existing sources and respondents may be unable to provide the required information. Also, obtained information might be unreliable, incomplete or weak in other aspects. This may hamper data collection efforts and may negatively influence the robustness of performed analyses.	We mitigated this risk by cross-checking with multiple sources. We monitored information sources that could be proven unreliable. We then aimed to understand the biases and collect similar information through other sources.
Limited access to informants	For both the online survey, as well as for the in-depth interviews, good access to informants is required. Limited access to these informants may hamper data collection efforts.	We mitigated this risk by approaching the potential informants at an early stage of the initiative, and by clearly underlining its nature and background. Moreover, the use of an accompanying support letter from the Commission/EASME encouraging potential informants to contribute to the project was made to increase the chance of their participation.
Informants' unwillingness to cooperate	Besides access to informants, their willingness to cooperate with the research team is crucial for the data collection efforts.	We mitigated this risk by means of clear and effective communication with potential informants through the established communication channels (see above). This risk was also mitigated by the quality and relevance of the questionnaires used in in-depth interviews and individual expert consultations. Moreover, we guaranteed impartiality in the analysis, as well as anonymity and security of data. Finally, the use of the abovementioned support letter from the Commission helped to decrease this risk.
Language Bias	Given that the current initiative aims to analyse inputs from various countries of the EU, we need to work with stakeholders speaking different languages. Language issues thus may represent a challenge, particularly for interviews.	The official language of data collection for this initiative is English. All reports for the Commission/EASME will be prepared in English. 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. For in-depth interviews and individual expert consultations, using English did

Risk	*Description*	*Mitigation measures*
		not prove to be an issue.
Unrepresentative sample of good practices	It is important to acknowledge that capturing all existing policies and initiatives is a utopian task (although we aim at making the analysis as complete as possible). Therefore, the cases analysed in this project should be seen as examples rather than a thorough representation of the whole population of policies and initiatives.	We are convinced that rather than trying to capture all existing initiatives, the primary added value of this Task comes from spotting the best practices that are suitable for upscaling to the European level (i.e., transferable to other contexts) and then translating those into specific policy recommendations and action points.
Risk of developing curricula guidelines that are not supported by the stakeholders	The curricula guidelines have to be driven and supported by all key stakeholder groups including industry, educators and policy makers. Only shared guidelines can be effectively translated into specific curricula and successfully implemented in practice since their actual implementation implies joint stakeholder efforts.	Rather than a product of the top-down approach, the guidelines need to be the result of stakeholder co-creation efforts in order to ensure its maximum practical relevance and acceptance by the relevant publics. Therefore, we aimed to maximise the engagement of stakeholders in the development of the guidelines by means of interactive workshops, interviews, and direct email and phone contact. Additionally, an online survey is scheduled for December 2018.
Risk of developing curricula guidelines setting contradictory directions	There is a risk of developing a long list of criteria that to a certain extent may contradict/neutralise each other and do not work in one direction.	When developing the guidelines, we aim to keep in mind that they have to offer an integrated approach towards advancing of the European KETs/AMT workforce. The approach needs to allow for the shift from sporadic fragmented activities towards a synergetic mix of directed actions at various levels (EU, MS, regional and institutional) with a shared goal in mind.
Risk of developing curriculum guidelines with too ambitious financial demands	There is a risk of developing guidelines for the curricula that are economically unfeasible to realise.	When developing the guidelines, we aim to keep in mind that they have to build on economically attractive solutions allowing for the optimal use of time, effort and cost.
Risk of developing curriculum guidelines that are not applicable to some cultural backgrounds	The KETs/AMT-related training and learning imply intensive cross-border cooperation. The ability to be applicable to multi-cultural environment is one of the key success factors.	When developing the guidelines, we aim to keep in mind that they have to be applicable to diverse cultural and geographical contexts and foster international cooperation.
Risk of developing rigid guidelines not allowing for future change	One of the key characteristics of the AMT domain is its tremendous pace of change. Developing solid 'set-in-stone' guidelines would	The guidelines have to set the general strategic orientation; however, they have to be flexible enough and allow for adjustments and future revisions. We aim at capturing the direction for

Risk	*Description*	*Mitigation measures*
	contradict the very nature of it.	development in the coming years, and operationalising it into a set of specific action points that could be relatively easily adjusted, if necessary.
Risk of developing curriculum guidelines that are not suitable for translation into specific actions	There is a risk of developing curriculum guidelines that are too conceptual for their practical implementation. The guidelines have to be suitable for the operationalisation into a set of specific action points for various relevant stakeholder groups at multiple levels (EC, MS, regions, educators and private stakeholders).	We aim to make sure the guidelines are practically oriented, written with the actual implementation in mind, and offer model examples of their implementation in practice.
Limited data available for KETs and AMT skills supply & demand update	The data available on KETs, let alone on KET skills, is highly limited. This, in turn, limits our ability to conduct a demand and supply analysis of KETs skills, both for estimating the state-of-play and for forecasting the future trend.	Given the data availability, we inevitably have to work with a number of assumptions to arrive at our estimates. To limit the risk as much as possible, we base our analysis on credible sources, openly report on our assumptions, seek stakeholder validation for our assumptions and estimates, and avoid using complex modelling that pose very strong restrictions on the data we can use.
Estimates of demand and supply of KET/AMT skills may turn out to be unreliable	The reliability of the estimates is rooted in a combination of methodology and data quality. If either one – or a combination of the two – is lacking, estimates will turn out unreliable and unfit for purpose. This risk is aggravated by the fact that there is only limited data available on KETs/AMT (see above).	Given the availability and quality of KET/AMT specific data available on skills, we aim to avoid complex modelling, since this would require a level of detail in the data that is not available. Moreover, while we have to work with a set of strong assumptions, we will openly communicate on the assumptions we take, actively seek expert feedback on our approach and results, and base our estimates on credible sources. We will also compare our estimates with key publications to verify the order of magnitude. Finally, we take a conservative approach in our estimates, limiting the potential for overestimation.
Dependability on external data	For both quality and timeliness of our skills demand and supply updates, we are highly dependent on external data sources (notably of CEDEFOP, Eurostat, KETs Observatory). If these sources do not deliver their updates (in a timely manner), then our demand and supply analysis will possibly	Having checked the key data sources, we noted that almost all of them contain updated data. The only source for which an update was still not available was the KETs Observatory (expected in November 2018 and coordinated by our project team). To this end, our demand and supply analysis had to be postponed till the end of 2018.

Risk	***Description***	***Mitigation measures***
	be delayed.	
Correlation analysis reveals a short time lag between enrolment and graduation, limiting our ability to use enrolments for better predicting future stock of graduates.	We will use simple correlation analysis to establish a link between study enrolment and graduation to better predict the future stock of KET/AMT graduates (i.e. future supply). If, however, little correlation is established or if the time lag between enrolment and graduation is rather small, the analysis would not present meaningful results for improving our estimates of future supply.	We note that in any case this is an explorative analysis which has not been conducted for KETs/AMT skills before. Therefore, we will need to assess the results once the analysis has been conducted. Nevertheless, if time lags are considered to be too short to provide meaningful extrapolation, then we can also start considering the broad literature on forecasting enrolment in specific study fields to better predict future stock of KET/AMT graduates. This would then be justified by a relatively short time lag and a high correlation, providing us an alternative as we go.
Mismatch between employment statistics generated for this contract vs. other KET initiatives (i.e. the KETs Observatory)	To estimate skills demand and supply, our analysis focusses on quantifying the people that possess the right set of skills. In essence, this comes down to estimating job demand and supply (i.e. employment; labour market). As different initiatives use different approaches for estimating employment in KETs, there is a risk that they do not align.	Our approach is designed to build on other key initiatives, limiting the extent to which the data are different. Nevertheless, we take a slightly different approach than particularly the KETs Observatory, by using more high-level assumptions to arrive at employment in KETs in the full value chain. The KETs Observatory, in contrast, focusses either on employment in manufacturing industries (too narrow) or in the wider economy (i.e. including suppliers of the value chain that includes workforce not necessarily demanding KET-specific skills; too wide). Inevitably, there will be differences between the approaches, but the risk can be mitigated by carefully explaining what it is that we are measuring.
Country-level analysis may incorrectly point at supply and demand concerns	As no data are available on migration flows of KET/AMT professionals, our country-level analysis may incorrectly identify skills imbalances (either positively or negatively) that are easily resolved across the (neighbouring) borders. Our analysis cannot control for this directly.	Although we cannot control directly for this, we acknowledge this concern by explicitly considering patterns in clusters of countries. That is why we will "colour code" the skills imbalances on a map of Europe, allowing us to identify regions where skills imbalances appear to be persistent. Furthermore, we will refrain from detailing our analysis on a year-by-year basis to even out strong micro-level fluctuations over time.

We have also performed a risk analysis for the remaining two work packages. Tables 6-2 and 6-3 present the outcomes of this analysis.

TABLE 6-2: Anticipated risks and proposed mitigation measures for WP2

Risk	***Description***	***Mitigation measures***

Risk	***Description***	***Mitigation measures***
Identifying 'usual suspects' (best practice curricula)	There is a risk of identifying not the most relevant best practices, but the educational & training offers that are most promoted.	To mitigate this risk, we aim at applying a targeted ranking system in order to shortlist the pre-selected curricula based on defined criteria.
Risk of developing in-depth descriptions of curricula, with a limited policy relevance	There is a risk of having descriptions 'for the sake of descriptions', without a clear added value	Our key objective when drafting the in-depth descriptions of best practice curricula will be to maximise their relevance for the future EU policy making. This principle defines the proposed structure of the analytical descriptions. We will pay special attention to the information collected 'from the field' on the suggestions for future EU policy making in the context of each best practice.
Risk of a low attendance rate of the workshops	There is a risk that the workshops will not be attended by a sufficient number of respondents.	In order to ensure active mobilisation of stakeholders, we aim at active collaboration with the key pan-European networks and communities, including networks of educators and training providers (VET, HE and on-the-job training), KETs-related industry associations, networks of policy makers focussed on education and employment policies, and other supporting communities. The workshops will be actively promoted among these communities; specific workshop participants will also be nominated by the coordinators of the abovementioned communities.
Risk of omitting certain key stakeholder groups	The key relevant stakeholder groups include education & training providers, companies, policy makers, as well as supporting structures (e.g. industry associations, unions and worker associations etc.) and learners. There is a risk that some of the key stakeholder groups will not be engaged in the activities of this initiative.	A wide stakeholder engagement strategy has been developed by the project team in order to make sure that all key stakeholder groups are included. The first step included mapping all the key stakeholder groups, which was followed by identifying the key communication channels and key messages to convey. Stakeholders will be reached by means of expert workshops, online surveys, individual consultations, and in-depth interviews. For ensuring a broad stakeholder coverage, the project team closely collaborates with the coordinators of relevant established networks and communities (e.g. relevant industry associations, research networks and unions and student associations).
Risk of having a 'too ambitious' design for the pan-European	There is a risk of developing plans and setting actions that would be difficult to realise in practice (e.g.	We aim at developing a pragmatic, effective and optimal approach that is based on the stakeholder input. We aim

Risk	*Description*	*Mitigation measures*
thematic network	due to lack of stakeholder commitment, lack of resources, too ambitious timing etc.).	to perform regular 'reality' checks with the relevant stakeholders, in order to make sure the proposed approach is feasible, commonly accepted and is likely to lead to measurable result. Besides individual email and phone communication, we aim at having individual expert consultations with the most active KSG members, for an in-depth discussion of the proposals and obtaining their feedback and suggestions.
Risk of low stakeholder response rate for the online survey and broader stakeholder consultation	There is a risk of low response rate for the online survey and broader stakeholder consultation.	We aim at making the process of filling in the survey as quick and easy as possible. To this end, we aim at designing the key questions in a closed manner (whenever possible), having predefined answer categories that the respondents can choose from. At the same time, the respondents will be offered multiple opportunities to provide their remarks (optionally).
Risk of not detecting incorrect results even after validation	There is a risk that the validation process will overlook certain imperfections in the data sourcing and its outputs.	We propose to apply a multi-level validation process consisting of three levels: (1) the internal validation by the project team; (2) the internal validation by the Commission/EASME, and (3) external validation by the key external experts (via online surveys, interviews, workshops and other channels).
Risk of overlooking important conclusions	Given a high amount of data and a high complexity of analysed topics, it will be a challenge to take into account all relevant trends and areas of attention when developing recommendations	Our approach is designed to extract the key priorities and to derive the recommendations aimed at the effective implementation and usage of curriculum guidelines and quality labels. We thus do not aim at developing a comprehensive picture of all possible support measures that could be introduced. However, if certain contextual points will be detected that are fundamental for the effective implementation of the curriculum guidelines and quality labels, we will also take them on board.

TABLE 6-3: Identified risks and proposed mitigation measures for WP3

Risk	*Description*	*Mitigation measures*
Risk of developing too generic implementation scenarios and a	There is a risk of approaching the implementation measures from a too generic perspective, not distinguishing between the target	To mitigate this risk, we aim at addressing the implementation scenarios and roadmaps separately for each target group (namely, technicians, tertiary

Risk	*Description*	*Mitigation measures*
general roadmap	groups and the context. Such approach is likely to result in diluted generic measures with a limited added value.	education students and on-the-job learners). Additionally, we aim to take into account the contextual specificity (i.e. commitment and level of development of a specific MS regarding the skills policy for KETs and AMT). We thus aim to develop tailor-made implementation plans for specific clusters of MS.
Risk of developing unconnected implementation scenarios for different phases of education & training	There is a risk of focussing on each specific target group, without addressing the connection between different phases of the life-long learning.	We aim to ensure the developed implementation scenarios and roadmaps are connected in a life-long learning model, where the formal education model is well aligned with the sub-sequent on-the-job training. Specifically, we aim to ensure that the actions to be taken for advancing the education of technicians and tertiary education students can be further complemented by the actions for the on-the-job training (as the next step in the life-long learning model).
Risk of low response rate to the public consultation	There is a risk of not obtaining the sufficient number of responses.	The questions of the consultation will be formulated in a way to make it user-friendly to complete. Procedures will be developed to promote the consultation among all the key stakeholder groups. We will reach out to a broader community using multiple communication channels.
Risk of facing challenges when preparing the final conference	Organising a conference for 100 participants is a complex activity requiring rigorous project management.	We will develop a detailed plan for the conference programme activities, including critical milestones, roles and responsibilities of the various Project Team members, dates and deliverables for the event. As part of the standard internal processes for the successful conference management, we will constantly monitor the accomplished tasks against the plan. PwC and ESN have extensive successful track record of organising high-level conferences.
Risk of failure of suppliers	An important success factor is the selection of reliable and experienced suppliers to provide the various services required: conference venue, catering, hostesses, suppliers of material (ICT equipment, badges, photocopiers, etc.).	We will follow a standard four-phase procedure for selecting suppliers: first selection criteria, quality control, liability, and risk assessment.
Risk of selecting inappropriate venue	There is a risk of selecting a venue that does not meet the	We will plan on-site visits before selecting an appropriate venue in order

Risk	*Description*	*Mitigation measures*
	requirements of the event.	to check its compliance with the conference programme's requirements, and to meet the suppliers and discuss various issues with them, which could affect the success of the event.
Limited communication and dissemination impact	There is a risk that insufficient number of stakeholders will be reached by the communication & dissemination activities	Stakeholder awareness will be ensured thanks to our extensive and thoroughly planned promotional and dissemination work.
Risk of a low attendance rate of the conference	There is a risk that the conference will not be attended by a sufficient number of respondents.	The conference will be actively promoted among the key stakeholder communities, including networks of education & training providers, industry associations representing KETs and AMT-related companies and particularly SMEs, and various support structures.
External data are not updated on time to be able to calculate an update of demand and supply within our timeframe	Given our high dependence on external data sources, there is a risk that for our second supply and demand skills update, no new data are timely available. Although CEDEFOP and Eurostat typically update their data annually, there is no guarantee that this will be the case. Moreover, no additional update of the KETs Observatory is yet foreseen beyond November 2018.	Being familiar with the methodology for calculating KETs skills demand and supply allows us to plan and conduct our second update relatively late in the service contract, if needed. We foresee to calculate the second update after publication of the revised data in June 2019.

6.2. Next steps

The second phase of this initiative (scheduled for January 2019 – December 2019) will concentrate on engaging a broader ecosystem of stakeholders, elaborating on recommendations and curriculum guidelines, and proposing concrete supporting measures. The final report will be released at the end of this phase.

Table 6-4 provides an overview of the key project milestones and their status.

TABLE 6-4: Key milestones and status

Actions/deliverables/meetings	*Deadlines*	*Status*
WP1: Structured collection of latest data and analysis		
Kick-off meeting	16 January 2018	*Completed*
Draft minutes of the Kick-off	22 January 2018	*Completed*

Actions/deliverables/meetings	***Deadlines***	***Status***
meeting		
Inception report	29 January 2018	*Completed*
Organising first expert workshop	12 June 2018	*Completed*
Organising second expert workshop	18 September 2018	*Completed*
Draft Interim Report	6 November 2018	*Completed*
First SC meeting	20 November 2018	*Completed*
Finalised Interim Report	4 December 2018	*Completed*
Organising third expert workshop	13 December 2018	*Completed*
WP2: Best practices, detailed elaboration of the curriculum guidelines and quality labels		
Organising fourth expert workshop	5 March 2019	In progress
Organising fifth expert workshop	18 June 2019	Not started yet
WP3: Validation, finalisation and dissemination		
Organising sixth expert workshop	17 September 2019	Not started yet
Draft Final Report	26 September 2019	Not started yet
Draft brochure	26 September 2019	Not started yet
Final SC meeting	10 October 2019	Not started yet
Finalised brochure	24 October 2019	Not started yet
Final conference	12 November 2019	Not started yet
Finalised Final Report	18 December 2019	Not started yet

Annex A: Overview of consulted stakeholders

TABLE A-1: Overview of consulted stakeholders (expert workshops, in-depth interviews and individual expert consultation)

Nr	Name	Organisation	Country
1.	*Esko Niemi*	Aalto University	Finland
2.	*Tessa van Puijenbroek*	TU Delft	Netherlands
3.	*Vincenzo Renda*	CECIMO	Belgium
4.	*Jan Harder*	Technical University of Munich	Germany
5.	*Jouke Verlinden*	TU Delft	Netherlands
6.	*Manuel Freitas*	MIT Portugal	Portugal
7.	*Wendy Miller*	AMRC Training Centre, the University of Sheffield	United Kingdom
8.	*Chris Decubber*	EFFRA	Belgium
9.	*Wieteke de Kogel*	Manufacturing Systems, University of Twente	Netherlands
10.	*Bogdan Dybała*	CAMT - Centre for Advanced Manufacturing Technologies	Poland
11.	*Carina Girvan*	Cardiff University	United Kingdom
12.	*Daniel Brissaud*	Grenoble Institute of Technology, KIC Added Value Manufacturing	France
13.	*Cecilia Berlin*	Chalmers University of Technology	Sweden
14.	*Annelies Raes*	KU Leuven	Belgium
15.	*Valerie Rocchi*	Grenoble Institute of Technology	France
16.	*Konstantinos Georgoulias*	University of Patras	Greece
17.	*Jivka Ovtcharova*	Karlsruhe Institute of Technology (KIT)	Germany
18.	*Ahmad Bsiesy*	CIME Nanotech	France
19.	*Anette Kolmos*	Aalborg University	Denmark
20.	*Agne Kudarauskiene*	Engineering Industries Association of Lithuania LINPRA	Lithuania
21.	*Björn Sautter*	FESTO	Germany
22.	*Harald Egner*	MTC	United Kingdom
23.	*Christian Warden*	MTC	United Kingdom
24.	*Jo De Groote*	Ziggzagg	Belgium
25.	*Roger De Keersmaecker*	RDK Consulting & Coaching	Belgium
26.	*Marcello Urgo*	Politecnico Di Milano	Italy
27.	*Mirko Scholz*	imec academy	Belgium
28.	*Damir Glas*	CECIMO	Belgium
29.	*Valentina Chanina*	EFVET	Belgium
30.	*Lisa Vittori*	Practical Robotics Institute Austria	Austria
31.	*Jouni Partanen*	Aalto University	Finland

Annex B: Examples of new/alternative approaches towards education & training in KETs and AMT

Already today, a number of institutions across the world begin to change. New models of education are emerging.

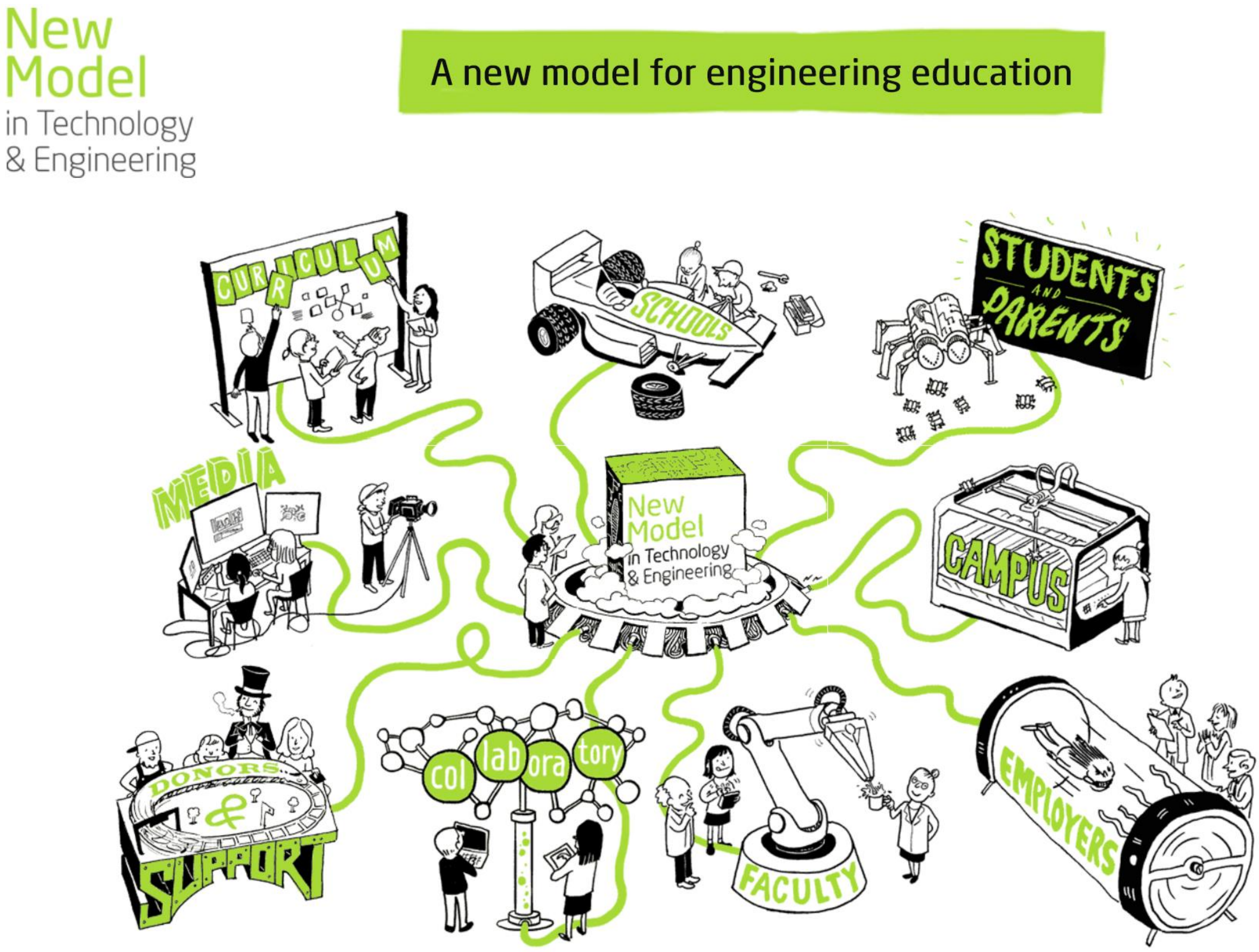


FIGURE B-1: A new model for engineering education by NMiTE[325]

Below we list some of the illustrative examples of the pioneers of these new educational approaches.

Olin College of Engineering (USA)[326]

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

325 http://nmite.org.uk/
326 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.

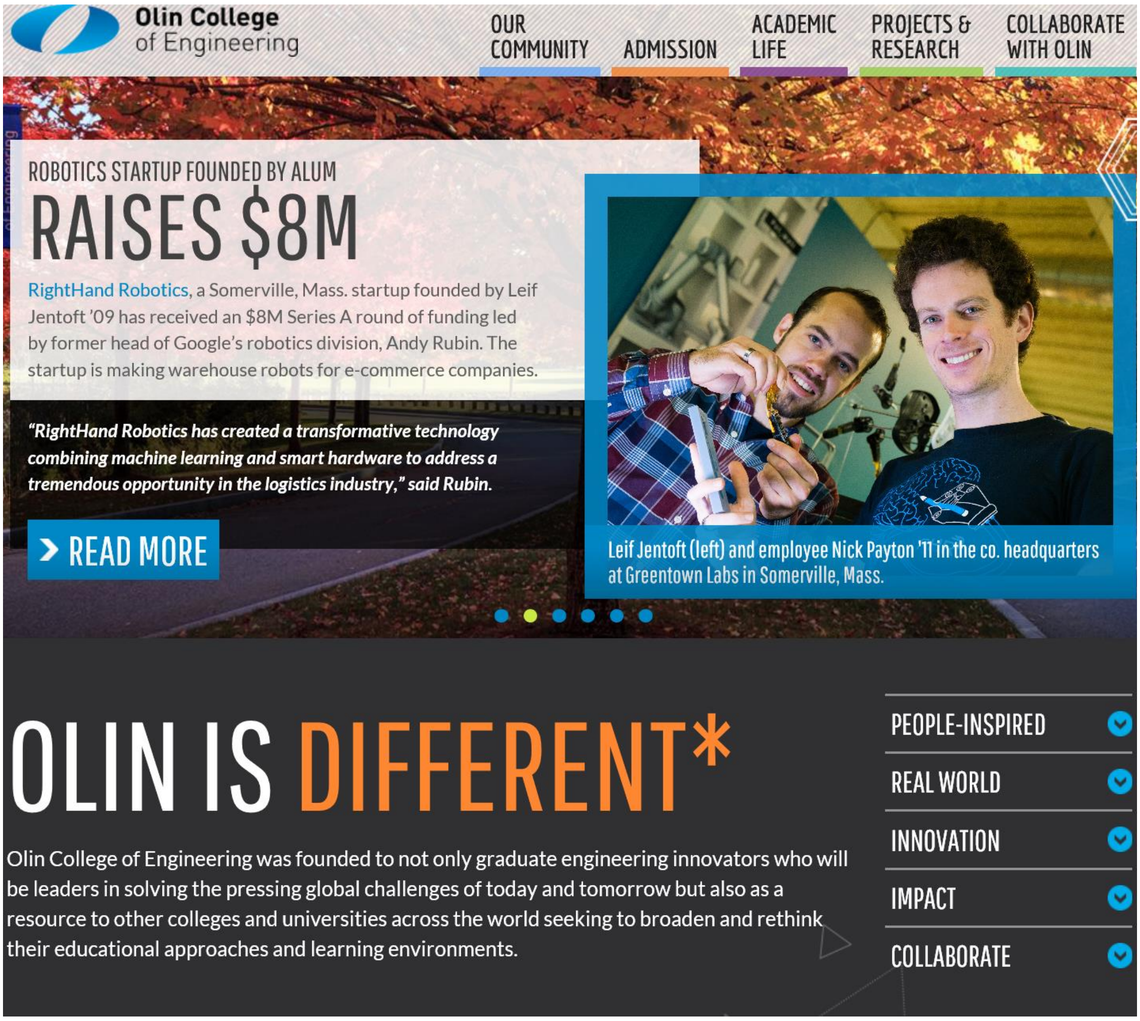


FIGURE B-2: Olin College of Engineering[327]

Aalborg University (Denmark)[328]

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.

327 http://www.olin.edu/discover-olin
328 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[329] **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 competences 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[330]:** 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

329 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
330 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[331]:** 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[332] **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 competences 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

331 The curriculum is organised around separate, specific subjects or disciplines. Based on the methodology of ABC Curriculum Resources, available at: http://gotootheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles

332 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[333]:** 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[334]:** 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)[335]

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.

NMiTE (United Kingdom)[336]

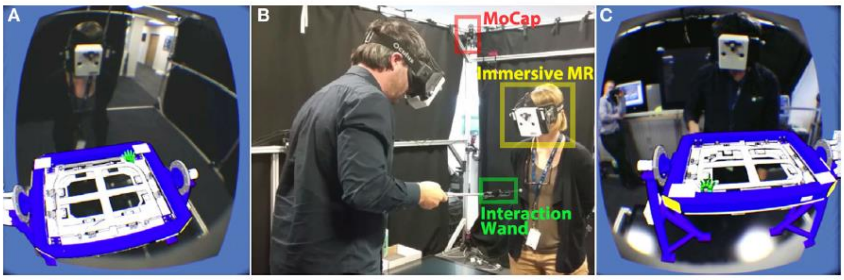
333 https://www.en.aau.dk/education/apply/master/finance-fees-master/#t295772
334 The curriculum is organised around separate, specific subjects or disciplines. Based on the methodology of ABC Curriculum Resources, available at: http://gototheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles
335 http://www.sutd.edu.sg/

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[337].

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[338]: 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 environment339.



| **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[340]

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[341].

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[342].

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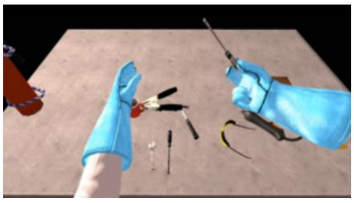
336 http://nmite.org.uk/
337 NESTA (2016) "The challenge-driven university: how real-life problems can fuel learning", by Mulgan G. and Townsley O., available at: https://www.nesta.org.uk/sites/default/files/the_challenge-driven_university.pdf
338 http://www.event-lab.org/
339 Gonzalez-Franco M. et al. (2017) "Immersive mixed reality for manufacturing training", Frontiers in Robotics and AI, published on 16 February 2017
340 Gonzalez-Franco M. et al. (2017) "Immersive mixed reality for manufacturing training", Frontiers in Robotics and AI, published on 16 February 2017
341 http://lightguidesys.com/blog/augmented-reality-training-tools-manufacturers/
342 http://lightguidesys.com/blog/augmented-reality-training-tools-manufacturers/

EIT Digital: new industrial virtual reality training tool[343] (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[344]: 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 project345: 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[346], edX[347], Udacity[348], and Futurelearn[349]. Courses in these platforms are typically designed around video lectures with in-video-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[350].

343 https://www.eitdigital.eu/newsroom/news/article/eit-digital-to-develop-new-industrial-virtual-reality-training-tool/
344 https://www.festo-didactic.com/int-en/
345 http://www.plattform-i40.de/I40/Redaktion/EN/Downloads/Publikation/digital-transformation-training.pdf;jsessionid=54D99194561981FACDF848B3D273B616?__blob=publicationFile&v=3
346 https://www.coursera.org/
347 https://www.edx.org/
348 https://www.udacity.com/
349 https://www.futurelearn.com/
350 http://www.elearning.dtu.dk/LEARN/Online-Courses-and-MOOCs

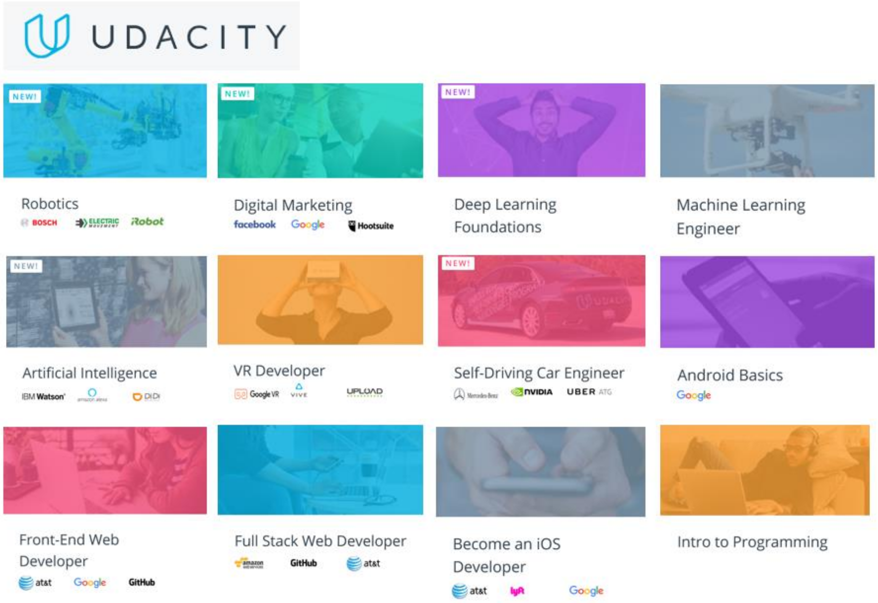


FIGURE B-4: Illustrative examples of available ICT- and KETs-related courses on Udacity ("nanodegree")[351]

…and many more…

351 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[352,353]:

- 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

352 PwC analysis incorporating multiple expert sources
353 CBInsights (2018) "Future Factory: How Technology Is Transforming Manufacturing". Retrieved October 15, 2018, from https://www.cbinsights.com/research/future-factory-manufacturing-tech-trends/

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 competences.

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[354,355,356,357]:

- 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

354 PwC analysis incorporating multiple expert sources
355 CBInsights. (2018). Future Factory: How Technology Is Transforming Manufacturing. Retrieved October 15, 2018, from https://www.cbinsights.com/research/future-factory-manufacturing-tech-trends/
356 Vaseekaran, A. (2018). The Critical And Evolving Role Of Contract Management In Digital Transformations. Retrieved October 15, 2018, from https://www.digitalistmag.com/finance/2018/01/16/critical-evolving-role-of-contract-management-in-digital-transformations-05754529
357 De Backer, K., Mercker, B., Moder, M., & Spiller, P. (2017). Purchasing power: Lean management creates new value in procurement. Retrieved October 15, 2018, from https://www.mckinsey.com/business-functions/operations/our-insights/purchasing-power-lean-management-creates-new-value-in-procurement#0

there are benefits to blended workforces where robots assist humans and humans assist robots to supercharge productivity[358]. In this context, the following technologies may be incorporated into the manufacturing environment[359,360,361]:

- 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[362]. 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

358 CBInsights. (2018). Future Factory: How Technology Is Transforming Manufacturing. Retrieved October 15, 2018, from https://www.cbinsights.com/research/future-factory-manufacturing-tech-trends/
359 PwC analysis incorporating multiple expert sources
360 CBInsights. (2018). Future Factory: How Technology Is Transforming Manufacturing. Retrieved October 15, 2018, from https://www.cbinsights.com/research/future-factory-manufacturing-tech-trends/
361 McCrea, B. (2017). Labor Management Systems Get "Smart." Retrieved October 15, 2018, from http://www.supplychain247.com/article/labor_management_systems_get_smart/Gartner
362 Kayser, H., Ey, M., Gerdemann, P., Kuz, S., Muller, J., Navrade, F., Sayed, M. (2017). Accelerating Labour Market Transformation. Retrieved October 15, 2018, from http://www.g20-insights.org/policy_briefs/accelerating-labour-market-transformation/

and customers. This is especially complex because approaches like just-in-time production, which optimises for high throughput but low idle inventory, requires a 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[363]. 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[364,365,366]:

- 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;

363 CBInsights. (2018). Future Factory: How Technology Is Transforming Manufacturing. Retrieved October 15, 2018, from https://www.cbinsights.com/research/future-factory-manufacturing-tech-trends/
364 PwC analysis incorporating multiple expert sources
365 Autodesk. (2018). Autodesk Generative Design. Retrieved October 15, 2018, from https://www.autodesk.com/solutions/generative-design/manufacturing
366 CBInsights. (2018). Future Factory: How Technology Is Transforming Manufacturing. Retrieved October 15, 2018, from https://www.cbinsights.com/research/future-factory-manufacturing-tech-trends/

- 3D printing (additive manufacturing) for custom designs, especially "no assembly required";
- 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[367]. 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[368]. 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

367 Kayser, H., Ey, M., Gerdemann, P., Kuz, S., Muller, J., Navrade, F., Sayed, M. (2017). Accelerating Labour Market Transformation. Retrieved October 15, 2018, from http://www.g20-insights.org/policy_briefs/accelerating-labour-market-transformation/

368 The Economist. (2012). Mapping the uncanny valley. Retrieved October 15, 2018, from https://www.economist.com/science-and-technology/2012/07/21/mapping-the-uncanny-valley

manufacturing. Here are some examples of how technology may be incorporated[369,370,371]:

- 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[372,373,374]:

369 PwC analysis incorporating multiple expert sources
370 CBInsights. (2018) "Future Factory: How Technology Is Transforming Manufacturing". Retrieved October 15, 2018, from https://www.cbinsights.com/research/future-factory-manufacturing-tech-trends/
371 Pettey, C. (2018) "Gartner Top 8 Supply Chain Technology Trends for 2018". Retrieved October 15, 2018, from https://www.gartner.com/smarterwithgartner/gartner-top-8-supply-chain-technology-trends-for-2018/
372 PwC analysis incorporating multiple expert sources

- Lights-out warehousing where there is no need for humans to store and retrieve items;
- Robotics for tasks like picking, sorting and palletising;
- 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[375]. For reference, the average factory has an OEE of about

373 CBInsights. (2018) "Future Factory: How Technology Is Transforming Manufacturing". Retrieved October 15, 2018, from https://www.cbinsights.com/research/future-factory-manufacturing-tech-trends/
374 RCS Logistics. (n.d.) "7 Ways in Which Technology Has Shaped the Warehousing and Distribution Industry". Retrieved October 15, 2018, from http://www.rcslogistics.co.uk/blog-and-news/7-ways-technology-has-haped-the-warehousing-and-distribution-industry/1273
375 CBInsights. (2018) "Future Factory: How Technology Is Transforming Manufacturing". Retrieved October 15, 2018, from https://www.cbinsights.com/research/future-factory-manufacturing-tech-trends/

60% whereas world-class manufacturing sites have an OEE of close to 85%[376]. Therefore, optimising this metric can best be achieved by incorporating more technology in the manufacturing environment, such as[377,378]:

- 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

376 CBInsights. (2018) "Future Factory: How Technology Is Transforming Manufacturing". Retrieved October 15, 2018, from https://www.cbinsights.com/research/future-factory-manufacturing-tech-trends/
377 PwC analysis incorporating multiple expert sources
378 CBInsights. (2018) "Future Factory: How Technology Is Transforming Manufacturing". Retrieved October 15, 2018, from https://www.cbinsights.com/research/future-factory-manufacturing-tech-trends/

companies and regulators, but also ultimately to clients and consumers as well. Technology may be incorporated in the following ways[379,380,381]:

- High density of IoT sensors and actuators combined with real-time synthesis of data streams to create “digital twins”;
- 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[382,383]:

- 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;

379 PwC analysis incorporating multiple expert sources
380 CBInsights. (2018) “Future Factory: How Technology Is Transforming Manufacturing”. Retrieved October 15, 2018, from https://www.cbinsights.com/research/future-factory-manufacturing-tech-trends/
381 Pilgrim Quality (2018) “Smart Quality Management: The Impact of Industry 4.0 on QMS”. Retrieved October 15, 2018, from http://blog.pilgrimquality.com/smart-quality-management-impact-industry/
382 PwC analysis incorporating multiple expert sources
383 Minturn, A. (2017) “Safety first: How Industry 4.0 can optimise safety”. Retrieved October 15, 2018, from http://www.controlengeurope.com/article/133867/Safety-first--How-Industry-4-0-can-optimise-safety.aspx

- 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;
- 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[384]. 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

384 Waslo, R., Lewis, T., Hajj, R., & Carton, R. (2017) "Industry 4.0 and cybersecurity". Retrieved October 15, 2018, from https://www2.deloitte.com/insights/us/en/focus/industry-4-0/cybersecurity-managing-risk-in-age-of-connected-production.html

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[385,386]:

- 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;
- 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[387]. 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[388,389]:

385 PwC analysis incorporating multiple expert sources

386 Waslo, R., Lewis, T., Hajj, R., & Carton, R. (2017) "Industry 4.0 and cybersecurity". Retrieved October 15, 2018, from https://www2.deloitte.com/insights/us/en/focus/industry-4-0/cybersecurity-managing-risk-in-age-of-connected-production.html

387 Tukker, A. (2004) "Eight Types of Product-Service System: Eight Ways to Sustainability? Business Strategy and the Environment, 13". Retrieved from http://sustainelectronics.illinois.edu/NSFworkshop/Reading/Eight Types of Product-Service System Eight Ways to Sustainability Experiences from Suspronet.pdf

388 PwC analysis incorporating multiple expert sources

389 Tukker, A. (2004). Eight Types of Product-Service System: Eight Ways to Sustainability? Business Strategy and the Environment, 13. Retrieved from http://sustainelectronics.illinois.edu/NSFworkshop/Reading/Eight Types of Product-Service System Eight Ways to Sustainability Experiences from Suspronet.pdf

- 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.

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[390]. 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[391,392]:

- 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;

390 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, from http://www.ipcc.ch/report/sr15/

391 PwC analysis incorporating multiple expert sources

392 Najouk, N., Le Fleming, H., & Srivatsav, N. (2018) “Digital Technology and Sustainability: Positive Mutual Reinforcement”. Retrieved October 15, 2018, from https://www.strategy-business.com/article/Digital-Technology-and-Sustainability-Positive-Mutual-Reinforcement?gko=37b5b

- 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;
- 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[393]. 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.

393 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, from http://pwc.blogs.com/sustainability/2017/06/industry-40-as-an-enabler-of-the-circular-economy.html

Annex D: Overview of abstracts from relevant scientific, policy and business publications

D.1. Relevant scientific publications

TABLE D-1: Overview of key scientific publications and abstracts per publication

Nr	Publication	Abstract
1.	Paravizo, E., Chaim, O. C., Braatz, D., Muschard, B., Rozenfeld, H. (2018) "**Exploring gamification to support manufacturing education on industry 4.0 as an enabler for innovation and sustainability**", Procedia Manufacturing, 21, pp. 438-445; https://doi.org/10.1016/j.promfg.2018.02.142	The issue of sustainability in productive processes has become one of the main challenges industries faces in the contemporary era. New industrial paradigms such as the Industry 4.0 point towards the creation of more sustainable processes. The transition process from traditional manufacturing to the Industry 4.0-ready manufacturers, however, presents a range of barriers which organizations must overcome. In this context, we look to the concept of gamification and the opportunities provided by this approach to help tackle such obstacles. In this paper, we expand the discussion on how gamification can be articulated to the Industry 4.0 transition context, aiming to develop a conceptual framework for gamification implementation tackling sustainability awareness issues. We argue that these gamification mechanics can contribute to support manufacturing education on Industry 4.0, enabling innovation and sustainability. Based on a systematic analysis of relevant literature, we verify that the sustainable manufacturing and Industry 4.0 topics were the least reported on having employed gamified applications. The proposed framework articulates gamification elements and sustainability requirements in the Industry 4.0 transition. This contribution may help companies on developing gamified applications to overcome some of the challenges they face regarding the sustainability aspect in the transition towards Industry 4.0.
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 https://doi.org/10.1016/j.cirp.2017.05.005	Learning factories present a promising environment for education, training and research, especially in manufacturing related areas which are a main driver for wealth creation in any nation. While numerous learning factories have been built in industry and academia in the last decades, a comprehensive scientific overview of the topic is still missing. This paper intends to close this gap by establishing the state of the art of learning factories. The motivations, historic background, and the didactic foundations of learning factories are outlined. Definitions of the term learning factory and the corresponding morphological model are provided. An overview of existing learning factory approaches in industry and academia is provided, showing the broad range of different applications and varying contents. The state of the art of learning factories curricula design and their use to enhance learning and research as well as potentials and limitations are presented. Conclusions and an outlook on further research priorities are offered.
3.	Despeisse, M., & Minshall, T. (2017) "**Skills and Education for Additive Manufacturing: A Review of Emerging Issues**", in IFIP International Conference on Advances in Production Management Systems (pp. 289-297). Springer, Cham.	The recent advances in digital technologies and in additive manufacturing (AM) in particular are revolutionising our industrial landscape. These changes require new engineering and management skills to exploit fully and sustainably the benefits offered by these advanced technologies. The current talent shortage calls for new education programmes to deliver a skilled, capable and adaptable workforce. Existing courses on design, engineering and management related to production and manufacturing do not systematically deliver the necessary skills and knowledge for an effective deployment of AM technologies. Based on a literature review and evidence collected from multi-stakeholder workshops, this paper presents the key themes for education programmes to address the current skill gap and barriers to AM adoption and exploitation.
4.	Gorecky, D., Khamis, M., Mura, K. (2017) "**Introduction and establishment of virtual training in the factory of the future**", International Journal of Computer Integrated Manufacturing, 30(1), pp. 182-190 doi: 10.1080/0951192X.2015.1067918	In order to make the factory of the future vision a reality, various requirements need to be met. There is a need to continuously qualify the human worker about new and changing technology trends since the human is the most flexible entity in the production system. This demands introducing novel approaches for knowledge-delivery and skill transfer. This paper introduces the design, implementation and evaluation of an advanced virtual training system, which has been developed in the EU-FP7 project VISTRA. The domain of interest is automotive manufacturing since it is one of the leading industries in adopting future factory concepts and technologies such as cyber-physical systems and internet of things. First of all, the authors motivate the topic based on the state-of-the-art concerning training systems for manual assembly and relevant technologies. Then, the main challenges and research questions are presented followed by the design and implementation of the VISTRA project including its methodologies. Furthermore, the results of experimental and technical evaluation of the system are described and discussed. In the conclusion, the authors give an outlook at the implementation and evaluation of the example

Nr	Publication	Abstract
		application in related industries.
5.	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.	Robotics education is one of the most emerged and demanding fields of modern engineering education. To prepare skilled specialists for industrial needs it is important to create high-quality educational base. Intelligent Robotics Department takes its first steps in developing and implementing a new robotics educational program. This paper reviews Russian robotics education and describes our current work toward program establishing. To evaluate student motivation of connecting their education and further career with robotics we ran a survey among bachelor and master students, which have selected robotics subjects as elective courses. We present results and analysis of the survey, and elaborate on next steps of program development.
6.	Mirkouei, A., Bhinge, R., McCoy, C., Haapala, K. R., Dornfeld, D. A. (2016) "**A Pedagogical Module Framework to improve Scaffolded Active Learning in Manufacturing Engineering Education**", Procedia Manufacturing, 5, pp.1128-1142 https://doi.org/10.1016/j.promfg.2016.08.088	Recent interest in improving pedagogical approaches in science, technology, engineering, and mathematics (STEM) fields has stimulated research at many universities. Several educational methodologies are reviewed in the context of manufacturing and through the lens of sustainability. It is found that there is a need to identify and understand the STEM educational challenges, and to assess the usefulness of existing methodologies using case-based analyses. In particular, this research aims to support student learning in manufacturing engineering through real-time process evaluations. A pedagogical framework is presented that can assist engineering educators in developing learning modules in support of this goal. The framework encompasses four steps: define the learning outcomes, create instructional resources, create active learning resources, and create a summative assessment mechanism. The framework emphasizes engagement of manufacturing engineering students in psychomotor learning, which remains a challenge due to the high cost of instructional laboratories. The framework is applied to develop a participatory pedagogy for manufacturing courses through the use of computer numerical control of manufacturing operations, and real-time monitoring, visualization, and data analysis of machine energy use. The framework is demonstrated for upper-level undergraduate and graduate manufacturing engineering courses at two universities (i.e., Computer-Aided Design and Manufacturing at Oregon State University and Precision Manufacturing at University of California, Berkeley). It is found that the framework can effectively support learning module development in manufacturing engineering education.
7.	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 https://doi.org/10.1016/j.addma.2016.03.001	The importance of additive manufacturing (AM) to the future of product design and manufacturing infrastructure demands educational programs tailored to embrace its fundamental principles and its innovative potential. Moreover, the breadth and depth of AM spans several traditional disciplines, presenting a challenge to instructors, along with the opportunity to integrate knowledge via creative and demanding projects. This paper presents our approach to teaching AM at the graduate and advanced undergraduate level, in the form of a 14-week course developed and taught at the Massachusetts Institute of Technology. The lectures begin with in-depth technical analysis of the major AM processes and machine technologies, then focus on special topics including design methods, machine controls, applications of AM to major industry needs, and emerging processes and materials. In lab sessions, students operate and characterize desktop AM machines, and work in teams to design and fabricate a bridge having maximum strength per unit weight while conforming to geometric constraints. The class culminates in a semester-long team design-build project. In a single semester of the course, teams created prototype machines for 3D printing of molten glass, 3D printing of soft-serve ice cream, robotic deposition of biodegradable material, direct-write deposition of continuous carbon fiber composites, large-area parallel extrusion of polymers, and in situ optical scanning during 3D printing. Several of these projects led to patent applications, follow-on research, and peer-reviewed publications. We conclude that AM education, while arguably rooted in mechanical engineering, is truly multidisciplinary, and that education programs must embrace this context. We also comment on student feedback, our experience as instructional staff, and our adaptation of this course to a manufacturing-focused master's degree program and a one-week professional short program.
8.	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.	In the last decade, numerous learning factories for education, training, and research have been built up in industry and academia. In recent years learning factory initiatives were elevated from a local to a European and then to a worldwide level. In 2014 the CIRP Collaborative Working Group (CWG) on Learning Factories enables a lively exchange on the topic "Learning Factories for future oriented research and

Nr	Publication	Abstract
	1-6 https://doi.org/10.1016/j.procir.2015.02.187	education in manufacturing". In this paper results of discussions inside the CWG are presented. First, what is meant by the term Learning Factory is outlined. Second, based on the definition a description model (morphology) for learning factories is presented. The morphology covers the most relevant characteristics and features of learning factories in seven dimensions. Third, following the morphology the actual variance of learning factory manifestations is shown in six learning factory application scenarios from industrial training over education to research. Finally, future prospects of the learning factory concept are presented.
9.	Choi, S., Jung, K., & Noh, S. D. (2015) "**Virtual reality applications in manufacturing industries: Past research, present findings, and future directions**", Concurrent Engineering, 23(1), 40-63.	Today, manufacturing industries are trying to improve their competitiveness by combining manufacturing per se with information technology. Virtual reality is being used in product development processes in manufacturing enterprises as a helpful technology to achieve rapid consolidation of information and decision-making through visualization and experience. In this article, 154 articles relevant to virtual reality's application to manufacturing were surveyed and analyzed. For this, (1) an analysis map was created, based on a virtual reality technology classification and the new product development process; (2) the articles investigated were located on the map; and (3) bibliometric analyses were carried out. Trends in past and present research were examined and future virtual reality research directions and application plans for manufacturing enterprises are discussed.
10.	Huang, Y. and Leu, M.C (2014), "**Frontiers of Additive Manufacturing Research and Education**", University of Florida, Report of NSF Additive Manufacturing Workshop	Based on the identified technology gaps and research needs, we have summarized our recommendations for AM technology and research in terms of materials, design, modeling, sensing and control, process innovation, and system integration. There is a tight coupling among material development, process development, process sensing and control, and the qualification and certification of products fabricated by AM. As in the progression of many other emerging technologies, the greatest advancements will come at the boundaries of fundamental material science, physics, biology, lasers, electronics, optics, metrology, and control. To provide the technological breakthroughs required to establish the new "certify-as-you-build" manufacturing paradigm, fundamental research and advanced development will be needed in order to handle the in situ diagnostics and control of AM processes by integrating modeling, sensing, and process control. For university-industry collaboration and technology transfer, our recommendations include incentivizing projects through federal funding, increasing federal research and development support, and increasing coordination efforts for public-private partnerships. For education and training, we recommend a university-community college partnership model with resource sharing and a teaching factory model to expose students directly to manufacturing enterprises. In addition, we recommend promoting the public awareness of AM, using the Internet to drastically increase outreach and resource sharing, and establishing publicly accessible AM facilities.
11.	Lewis, P. (2014) "**The over-training of apprentices by employers in advanced manufacturing: a theoretical and policy analysis**", Human Resource Management Journal, 24(4), pp. 496-513 https://doi.org/10.1111/1748-8583.12039	This article reports the results of a study of the 'over-training' of apprentices by large manufacturers in the UK. The term 'over-training' was traditionally used to refer to the way in which nationalised industries trained more apprentices than they needed, with the 'surplus' being released at the end of their training to find another employer. In contrast, the evidence reported in this article indicates that over-training now typically involves large employers helping to train apprentices who are employed and paid by other firms from the outset. The project examines the extent and nature of over-training, the reasons why employers become involved in over-training, and policy implications. The evidence suggests that over-training can increase the number of high-quality apprenticeships. Large employers need to be made more aware of over-training. Government can help promote over-training via its 'Catapult Centres'.
12.	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 https://doi.org/10.1016/j.procir.2014.01.057	More and more educational organizations promote hands-on training models to prepare their students for professional life. Also in the field of engineering the application of case studies and business games is becoming more common, which are intended to simulate the situation in real life giving the students the opportunity to apply their theoretical knowledge in practice. Some universities have just proven the use of so-called "learning factories" in addition to the traditional classroom environment for teaching in planning and the design of flexible manufacturing systems. These learning factories correspond to small and flexible production and assembly units for practice and for training. The Faculty of Science and Technology of the Free University of Bolzano decided in 2012 to set up a learning factory named "mini-factory" with the scope of a more practice-oriented education in engineering. This paper shows the concept of the "mini-factory" and the impressions and

Nr	Publication	Abstract
		results of its application in the lectures. In addition, the paper gives an outlook of the collaboration between university and business giving also to small and medium sized enterprises the opportunity to qualify their personal in the mini-factory infrastructure.
13.	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. doi:10.1109/LaTiCE.2014.47	Lack of real problem or industrial exposure causes the students in technical education to face difficulties in understanding their lessons and also cause inadequate practical hands-on skill of the students. Since they are the future generation of the country and will become the employees in the industry, lacking in knowledge, practical hands-on skills and generic skills will affect the development of the country. A study in several countries has shown that institutions which implement industrial experience programs to simulate a real working environment produce students with real experience and have better skills and expertise. The aims of this study are to review the existing learning models for PBET, and to examine the components of PBET model in technical education. The identified components can be used to propose a strategic framework for promoting active learning which can enhance students' competency and professional skill.
14.	Wong, D. S. K., Zaw, H. M., Tao, Z. J. (2014) "**Additive manufacturing teaching factory: driving applied learning to industry solutions**", Virtual and Physical Prototyping, 9:4, pp. 205-212 doi: 10.1080/17452759.2014.950487	This paper details how Nanyang Polytechnic has applied its Teaching Factory Concept in training its students and industry personnel on relevant additive manufacturing technologies with real industry applications. It also briefs on its additive manufacturing journey of capability development, industry projects and applied R&D activities over the last 20 years in alignment with the changing industry needs and trends in Singapore. It concludes with some industry case studies to demonstrate the impact and value-adding benefits to industry, leveraging on the additive manufacturing competencies.
15.	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 https://doi.org/10.1016/j.procir.2014.01.126	The importance of leveraging manufacturing teaching and training up to the standards of the current and future needs is obvious. Recent studies have pointed out the urgent need for future engineers and knowledge workers to adopt teaching curricula in order to be prepared to cope with the increasing industrial requirements of the factories of the future. The current study presents the evolution of the Teaching Factory concept and its application to a real-life pilot. The Teaching Factory paradigm comprises the industrial project, the relevant educational approach and the necessary ICT configuration for the facilitation of interaction between industry and academia. The current status of the paradigm is tested on a real-life pilot, between a university and a construction equipment factory. The conclusions of the pilot, show the promising nature of the Teaching Factory and the numerous benefits accruing, both for academia and industry.
16.	Mavrikios, D., Papakostas, N., Mourtzis, C. (2013) "**On industrial learning and training for the factories of the future: a conceptual, cognitive and technology framework**", Journal of Intelligent Manufacturing, 24(3), pp. 473-485 https://doi.org/10.1007/s10845-011-0590-9	The manufacturing education addresses significant challenges in view of paving the way for the human capital of the Factories of the Future. This paper introduces a specification framework for the delivery of industrial learning and training, addressing the needs for the "knowledge" workers of the factories of the future. A review of the relevant background, including the activities associated with the industrial learning and its basic methods as well as some emerging paradigms, is first provided. A Teaching Factory based paradigm is then suggested as the conceptual foundation of this framework. A cognitive framework, addressing the major building blocks of the industrial learning process, namely the attitude the knowledge the skills and the competences is being defined. An appropriate technology framework, dealing with the needs of engineers and blue-collar workers, for practicing the manufacturing knowledge content within digital environments, is suggested at this point. Finally, the approach of the future implementation of the specific framework is being discussed.
17.	Chryssolouris, G., Mavrikios, D., Mourtzis, D. (2013) "**Manufacturing systems: skills & competencies for the future**", Procedia CIRP, 7, pp. 17-24 https://doi.org/10.1016/j.procir.2013.05.004	Recent studies have presented clear evidence of the relationship between human capital qualifications and competitiveness. At the same time, there have been frequent reports on the shortage of skilled manufacturing personnel. This paper introduces some approaches to building skills and competences in manufacturing. The importance of human capital skills for industry's competitiveness is first discussed, providing an overview of the current situation in different world regions. Modern approaches to manufacturing education are shortly reviewed. The need for young people to be enlightened about the exciting character of manufacturing, with real life problems being addressed under business conditions, via scientific approaches and cutting edge technologies, is discussed. A "Teaching Factory" paradigm is being introduced as a distance-learning knowledge delivery mechanism of bringing the real factory into the classroom. The activities of the KNOW-FACT project aiming to deliver a pilot implementation of the Teaching

Nr	Publication	Abstract
		Factory paradigm as a 2-way "learning channel" connecting industry and academia are further discussed.
18.	Jovanovic, V., Hartman, N.W. (2013) "**Web-based virtual learning for digital manufacturing fundamentals for automotive workforce training**", International Journal of Continuing Engineering Education and Life-Long Learning, 23, pp.300–310	Automotive manufacturers are experiencing difficulties in hiring highly qualified workers with ability to adopt new technologies fast. This kind of ongoing need for training is slowing innovation. This problem is related to the difficulty in obtaining consistent training resources and services especially with lack of training for advanced manufacturing practices for specialised industry sectors. More and more occupations require degrees higher than secondary education because of the global need for so called 'knowledge workers'. An example of an interactive learning programme, developed with the support of narrated presentation technology, podcasts and online access has been shown in this paper. Sixty nine online modules have been developed during the course of a project funded by Department of Labor for automotive sector. These online modules have been developed for lifelong learners to be used and accessed at any time (asynchronously from a website). Curriculum modules, developed for the Introduction to Digital Manufacturing are a part of a certificate programme which expands the pool of skilled workers, enhance the abilities of incumbent workers, and strengthen the entire advanced manufacturing sector.
19.	Gorecky, D., Mura, K., Arlt, F. (2013) "**A Vision on Training and Knowledge Sharing Applications in Future Factories**", IFAC Proceedings Volumes, 46(15), pp. 90-97 https://doi.org/10.3182/20130811-5-US-2037.00019	Under the pressure of global technological, social and economic changes, manufacturing enterprises require to invest in the advanced training of their employees. The technological basis for new forms of training and knowledge sharing concepts is created by advances in information and communication technology (ICT) and human-computer interaction (HMI). The paper provides an overview about the vision on human-centered production from the perspective of the EU-FP7 project VISTRA. The relevant state-of-the-art for training and knowledge sharing systems is described and the future trends and requirements are anticipated. On the example of the vehicle industry the qualification requirements are stated and transferred into two visionary systems for knowledge-delivery and skill transfer.

D.2. Relevant policy and business publications

Abstracts are provided whenever available. In case abstracts were not available, we have developed a short summary.

TABLE D-2: Overview of key policy and business publications and abstracts per publication

Nr	Publication	Abstract/summary
1.	Pei, E., Monzón, M., Bernard, A. (2018) "**Additive Manufacturing - Developments in Training and Education**", Springer	This book provides an overview of training and teaching methods, as well as education strategies, for Additive Manufacturing (AM) and its application in different business sectors. It presents real-world applications and case studies to demonstrate the key practical and theoretical fundamentals of AM training, written by international experts from the field. The book's contributors discuss many topics to provide readers a fundamental grasp of AM, including: collaboration among educational bodies, and between industry and governments, strategies for implementing AM training, new teaching methods, training programs that provide alternative employment choices, the need for certification by professional bodies, and promoting awareness of AM in society.
2.	Magid, E., Sabirova, L., Tsoy, T. (2017) "**Towards Effective Interactive Teaching and Learning Strategies in Robotics Education**", 10th International Conference on Developments in eSystems Engineering (DeSG)	Robotics education is one of the most emerged and demanding fields of modern engineering education. To prepare skilled specialists for industrial needs it is important to create high-quality educational base. Intelligent Robotics Department takes its first steps in developing and implementing a new robotics educational program. This paper reviews Russian robotics education and describes our current work toward program establishing. To evaluate student motivation of connecting their education and further career with robotics we ran a survey among bachelor and master students, which have selected robotics subjects as elective courses. The answers indicated an increased interest of students in robotics. Based on the analysis results, the researchers concluded that the combination of teaching methods, courses content and teaching in English language gave positive results in students' motivation to study robotics. *[Last paragraph added by PwC]*
3.	Dumitrescu, E., Feige, E., Lacopeta, C., Radermacher, A. (2017) "**To make a transformation succeed, invest in capability building**", McKinsey & Company	Manufacturers need new types of employees, such as data scientists and cloud computing specialists. Overall, companies need talents with more complex skill profiles and employees who combine functional, technical and leadership competencies. Furthermore, companies need to build these capabilities fast, but outside hires is not enough. Current employees will need training as well. McKinsey identify four key elements for success: Building the capabilities that matter the most, tailor training, use adult leaning principles and measure and track process. McKinsey further offers advise on design, implementation and sustaining the gains from training. *[Summary provided by PwC]*
4.	Despeisse, M., Minshall, T. (2017) "**Skills and Education for Additive Manufacturing: A Review of Emerging Issues**", IFIP Advances in Information and Communication Technology	The recent advances in digital technologies and in additive manufacturing (AM) in particular are revolutionising our industrial landscape. These changes require new engineering and management skills to exploit fully and sustainably the benefits offered by these advanced technologies. The current talent shortage calls for new education programmes to deliver a skilled, capable and adaptable workforce. Existing courses on design, engineering and management related to production and manufacturing do not systematically deliver the necessary skills and knowledge for an effective deployment of AM technologies. Based on a literature review and evidence collected from multi-stakeholder workshops, this paper presents the key themes for education programmes to address the current skill gap and barriers to AM adoption and exploitation.
5.	Swearer, R. (2016) "**Why Manufacturing Education Needs to Advance, just like you have**", Industry Weekly, published on Aug. 23rd 2018	Stuck in the Industrial Age, skills training does not place enough emphasis on smart, connected product manufacturing, advanced material development and digital design integration. Three suggestions are presented to build a more advanced and dynamic workforce: Create hands-on opportunities within education systems (business-university cooperation, collaborative learning), focus on real-world application of skills (redefining success in education, new use of learning platforms, and develop and elevate micro-credentialing programs for students and employees (recognition of accomplishments outside school). *[Summary provided by PwC]*
6.	PwC, Manufacturing Institute (2016) "**Upskilling manufacturing: How Technology is disrupting**	What are the paths US manufacturers can take to nurture a future talent pipeline with the skills needed to take advantage of today's technological advances and, most important, to be prepared for those, now unseen, that will emerge in the future. Most manufacturers today

Nr	Publication	Abstract/summary
	America's industrial labor force", PwC	train their employees in the work place to upskill their workforce, but also outside workplace training is increasing in use. The same is the recruitment of STEM graduates. Possible developments are recruitment from outside the industry and apprenticeships. *[Summary provided by PwC]*
7.	VDI (2015) "**A Discussion of Qualifications and Skills in the Factory of the Future: A German and American Perspective**", VDI	Research the development needs of the workforce in the factory of the future, to identify the current challenges, and to recommend initiatives to prepare the future workforce for changes in their work environment. The ongoing initiatives of the Advanced Manufacturing Program and Industry 4.0 led by the United States and Germany respectively were reviewed to identify areas for joint collaborative efforts and prepare industry for the technology and workforce demands of the factory of the future. It can be seen that different technical and personal qualifications and skills become important: On the technical side, especially skills and qualifications with respect to IT, information and data processing and analytics, an organizational and process understanding, and the ability to work and interact with modern interfaces are prospectively of high value for the skilled labour. Due to the omnipresence of information and data and the integration of different business processes, the workers need to gain knowledge management abilities and an interdisciplinary understanding of their organization, its processes and used technologies. Additionally, a certain sensitivity for IT security and data protection will be mandatory. Technical skills that will definitely be useful, yet not necessarily required are for example computer programming or coding abilities or similar very deep technical knowledge. The factory worker of the future will be more a generalist than a specialist. Soft skills such as social and communication skills as well as team working and self-management abilities, which are all skills managers and engineers are currently trained at, become very important for the skilled labour as well. Currently, the typical factory worker does not enjoy training in those areas because the job content does usually not necessitate the application of these skills. However, in a factory of the future, there will not only be significantly more teamwork on the shop floor level but also more teamwork and communication in daily business.
8.	Djuric, A., Jovanovic, V., Goris, T. (2015) "**Preparing students for the advanced manufacturing environment through robotics, mechatronics and automation training**", ASEE Annual Conference and Exposition, Conference Proceedings. 122.	Various engineering technology departments offer different courses related to the application of robotics. These courses are a great way to inspire students to learn about science, math, engineering, and technology while providing them with workforce skills. However, some challenges are present in the delivery of such courses. One of these challenges includes the enrolment of students who come from different engineering departments and backgrounds. Such a multidisciplinary group of students can pose a challenge for the instructor to successfully develop the courses and match the content to different learning styles and math levels. To overcome that challenge, and to spark students' interest, the certified education robot training can greatly support the teaching of basic and advanced topics in robotics, kinematics, dynamics, control, modelling, design, CAD/CAM, vision, manufacturing systems, simulation, automation, and mechatronics. This paper will explain how effective this course can be in unifying different engineering disciplines when using problem solving related to various important manufacturing automaton problems. These courses are focused on educational innovations related to the development of student competency in the use of equipment and tools common to the discipline, and associated curriculum development at three public institutions, in three different departments of mechanical engineering technology. Through these courses students make connections between the theory and real industrial applications. This aspect is especially important for tactile or kinesthetic learners who learn through experiencing and doing things. They apply real mathematical models and understand physical implications through labs on industrial grade robotic equipment and mobile robots.
9.	Barber, M., Hill, P. (2014) "**Preparing for a Renaissance in Assessment**", Pearson	The publication argument that an educational revolution will lead to certain long-held beliefs and ways of doing things will be replaced by a new set of beliefs and practices. For the educational revolution to happen, we will have to change our views on the students' capacity to learn and profit from formal education, what students needs to learn, the focus on educational policy, the basic organisation of schooling, how students will learn and how teachers will teach and the emergence of teaching as a profession. In the case of formal assessment programmes design primarily for

Nr	Publication	Abstract/summary
		certification, selection and accountability purposes, there is the prospect of creating tests and examinations that assess the full range of student abilities, provide more meaningful information on learning outcomes, assess the full range of valued outcomes, motivate improvement efforts and minimise opportunities for cheating. *[Summary provided by PwC]*
10.	Davenport, T. H. (2013) "**The Future of the Manufacturing Workforce**", Manpower	This report has explored the critical role of the "tech," or manufacturing technical worker, in the contemporary manufacturing industry. The rise of computer-based devices and manufacturing automation in plants has led to a need for sophisticated technical workers to program, operate, and maintain these technologies. There are not enough techs available to fill the current need, and the requirements for these roles will only increase. Leading companies are beginning to work closely with educational institutions to develop programs that would train techs. Education and training are, of course, the keys to closing the manufacturing talent gap. While there are several examples of innovation in manufacturing technology education by single institutions, they are still too small and fragmented to meet the demand levels of employers. There are also isolated examples of small networks of educational institutions, and of progressive employers. All of these need to be undertaken on a larger scale. The solution to this problem will require concerted – and connected – efforts by government, employers, schools, and individuals themselves. There is also a need for substantial change in the cultural image of the manufacturing industry and of careers in it. *[Summary provided by PwC]*

ANNEX E: GOOD PRACTICE CURRICULUM DESCRIPTIONS

E.1. Manufacturing Engineering Tripos, University of Cambridge (UK)

TABLE E-1: Manufacturing Engineering Tripos, University of Cambridge (UK)

Nr	Item	Description
1.	***General characteristics***	**Title:** Manufacturing Engineering Tripos (MET)[394] **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[395]. 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[396]. Tuition fee for overseas students commencing in October 2019 is GBP 30,678 per year[397]. 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

394 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
395 https://www.undergraduate.study.cam.ac.uk/fees-and-finance/tuition-fees
396 https://www.undergraduate.study.cam.ac.uk/why-cambridge/support/mature-students/second-undergraduate-degrees
397 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[398]:** 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[399]

E.2. MSc. Industrial Systems, Manufacturing and Management (ISMM), University of Cambridge (UK)

TABLE E-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)[400] **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[401]:** 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.

398 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
399 http://www.information-hub.admin.cam.ac.uk/university-profile/ug-examination-results/results-course-dashboard data collected Oct. 23rd 2018
400 The course webpage is source of information unless otherwise stated. https://www.ifm.eng.cam.ac.uk/education/ismm/course-overview/
401 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[402]:** 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[403]

E.3. BSc. Industrial Design Engineering, Delft University of Technology (Netherlands)

TABLE E-3: BSc. Industrial Design Engineering, Delft University of Technology (Netherlands)

Nr	Item	Description
1.	***General characteristics***	**Title:** BSc. Industrial Design Engineering[404] **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

402 The curriculum is organised around separate, specific subjects or disciplines. Based on the methodology of ABC Curriculum Resources, available at: http://gotootheexchange.ca/index.php/curriculum-overview/curriculum-models-and-design-principles

403 https://www.prao.admin.cam.ac.uk/data-analysis-planning/student-numbers/snapshot-courseschooldepartment

404 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[405]:** 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[406]:** 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.

405 https://www.tudelft.nl/en/education/practical-matters/tuition-fee-finances/

406 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.

E.4. MSc. Mechanical Engineering, Delft University of Technology (Netherlands)

TABLE E-4: MSc. Mechanical Engineering, Delft University of Technology (Netherlands)

Nr	Item	Description
1.	***General characteristics***	**Title:** MSc. Mechanical Engineering[407] **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[408]:** 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[409]:** 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.

407 The course webpage is used as source unless otherwise stated. https://www.tudelft.nl/en/education/programmes/masters/mechanical-engineering/msc-mechanical-engineering/
408 https://www.tudelft.nl/en/education/practical-matters/tuition-fee-finances/
409 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

E.5. BSc. Industrial Production Engineering, Politecnico di Milano (Italy)

TABLE E-5: BSc. Industrial Production Engineering, Politecnico di Milano (Italy)

Nr	Item	Description
1.	***General characteristics***	**Title:** BSc. Industrial Production Engineering[410] **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[411]:** 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[412]. One of the offered specialisations further elaborates in the management perspective of manufacturing.

410 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

411 https://www.polimi.it/en/current-students/tuition-fees-scholarships-and-financial-aid/student-contribution/

412 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[413]. • **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[414]:** 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.

E.6. Global Master in Industrial Management, Politecnico di Milano (Italy)

TABLE E-6: Global Master in Industrial Management, Politecnico di Milano (Italy)

Nr	Item	Description
1.	***General characteristics***	**Title:** Global Master in Industrial Management (GMIM)[415] **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

413 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

414 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

415 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[416]:** 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.

416 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

E.7. BSc Materials and Process Engineering Specialisation, RWTH Aachen University (Germany)

TABLE E-7: BSc. Materials and Process Engineering Specialisation, RWTH Aachen University (Germany)

Nr	Item	Description
1.	***General characteristics***	**Title:** BSc. Materials and Process Engineering Specialization[417] **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[418].
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[419]:** This subject offers a broad combination of basic natural science subjects and engineering fundamentals. Students do not specialise in order to take advantage of

417 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
418 http://www.rwth-aachen.de/go/id/bqmo/lidx/1
419 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.

E.8. MSc. Materials and Process Engineering Specialisation, RWTH Aachen University (Germany)

TABLE E-8: MSc. Materials and Process Engineering Specialisation, RWTH Aachen University (Germany)

Nr	Item	Description
1.	***General characteristics***	**Title:** MSc. Materials and Process Engineering Specialization[420] **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[421].
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

420 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
421 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[422]:** 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.

E.9. BSc. Mechanical Engineering, KTH Royal Institute of Technology (Sweden)

TABLE E-9: BSc. Mechanical Engineering, KTH Royal Institute of Technology (Sweden)

Nr	Item	Description
1.	***General characteristics***	**Title:** BSc. Mechanical Engineering (CMAST)[423] **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[424]:** 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.

422 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
423 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
424 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[425]:** 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.

E.10. MSc. Production Engineering and Management, KTH Royal Institute of Technology (Sweden)

TABLE E-10: MSc. Production Engineering and Management, KTH Royal Institute of Technology (Sweden)

Nr	Item	Description
1.	***General characteristics***	**Title:** MSc. Production Engineering and Management[426] **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

425 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

426 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
		of resources that are essential for achieving a sustainable production 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[427]:** 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.

427 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

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