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# Operational Guideline on Context and Training Tools

***Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B***

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## Contents

## 1. Executive Summary

SAM (Sector Skills Strategy in Additive Manufacturing) project, aims to deliver together with all partners and stakeholders a shared vision and collaborative skill solutions capable to foster and support the growth, innovation and competitiveness in the Additive Manufacturing (AM) sector.

Work package (WP) 3 is composed of three deliverables (Figure 1) settling the methodology for design and review of professional profiles, qualifications, and Units of learning outcomes. This deliverable reports the third part of the work done in Work Package 3, following the proposed methodology for creating and revising professional profiles (D3.1) and the kits and templates to apply this methodology ( D3.2).

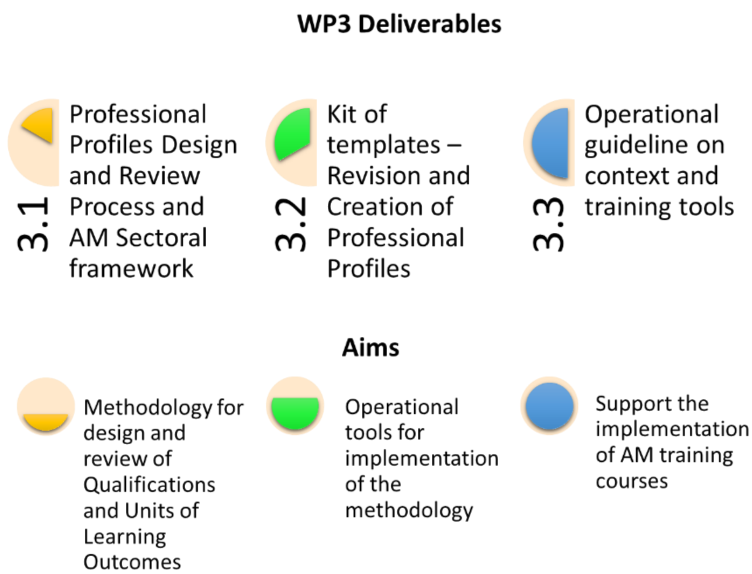


Figure 1: WP3 Deliverables overview

The main contribution of this document is to map and assess training contexts and training tools that match the learning outcomes of qualifications. Learning context is defined as the situation in which learning or understanding is taking place. Training tools are all those programs, platforms, or templates that help trainers deliver their training to their learners. In 2008, the EQF defined learning outcomes as statements of what a learner knows, understands and is able to do on completion of a learning process, which may be defined in terms of knowledge, skills, and competence. This can be especially important for assessment and evaluation in order to assess the knowledge. In case of the SAM project, the learning outcomes will be specified as skills and knowledge. Often, "Bloom's Taxonomy" is used to describe the knowledge and skills. This model is a hierarchical model that categorizes learning objectives into varying levels of complexity, from basic knowledge and comprehension to advanced evaluation and creation. It contains a list and description of in-use learning contexts and training tools in AM training. For every training context/tool, there is a description of its "advantages", "constraints", and "recommendation for being used in AM training", which give a good insight on how well each context/tool might contribute to AM training/teaching. In addition, the deliverable benefits from data collected by means of the survey for training centres to show the status of in-demand skills, namely digital and green skills, which are being taught in existing AM courses. Finally, in the last section some examples of training and learning tools from SAM partners support the results from the document analysis, which are discussed in previous sections.

## 2. Introduction

The global AM market was worth $9.3 billion in 2018, growing rapidly 18% since the year before, according to SmarTech Publishing, a leading 3D printing analysis firm (1) (for example 3DPrint.com owner, 3DR Holdings, has acquired an interest in SmarTech Markets Publishing; the Leading Industry Analysis Firm in the Additive Manufacturing Sector. SmarTech Publishing is the only firm providing granular market analysis for the 3D printing/additive manufacturing industry). Moreover, in a recent study, Deloitte indicates that the industry is growing at an even faster rate and that the global AM market is expected to grow past $21 billion in revenue by (2). At the same time, the Society of Manufacturing Engineers (SME) found nine out of ten manufacturers have difficulty in (3). Therefore, the need for AM education and professional training is urgently needed to enable AM industry growth.

Following the main efforts conducted in the previous tasks of this work package, which include the definition of a methodology to design and review professional profiles in Additive Manufacturing (AM), this deliverable aims providing an overview of training contexts and tools which will allow stakeholders to implement the professional profiles within a real case scenario. The focus is on the specific learning/teaching contexts that fit well with AM education/training programs, as well as the training tools that support trainees/learners in achieving specific learning outcomes.

This deliverable, together with D3.1 and D3.2, provides a tool kit including the methodology for creation and revision professional profile, a kit of templates to apply this methodology, and a map of training context/tools that enables WP5 and WP6 to move one step forward during the implementation of pilot courses.

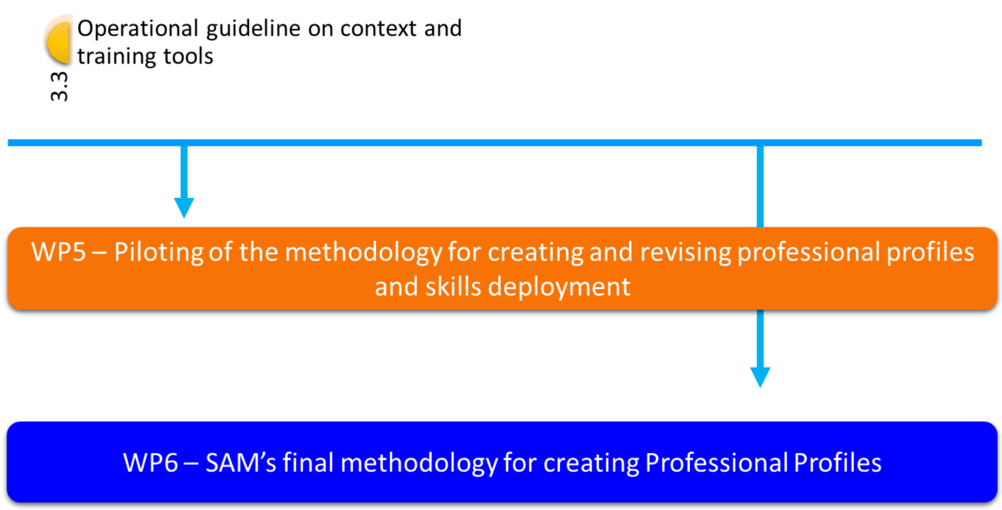


Figure 2: Interaction flow between D3.3 and remaining project outcomes

To fully explore the availability of specific AM learning and teaching contexts, the document aims at studying the current state of the learning contexts and training tools in AM available. Accordingly, the review is divided in two main sections focused on learning contexts (Section 3) and learning tools (Section 4) respectively. At the end of each section an overview of positive and negative aspects of each context or tool is outlined. An overview of the different relevant European initiatives concerning education in AM is given in Section 5. Finally, direct experience of SAM partners, which can be considered as leading organizations operating in the European AM field, are described in Section 6.

# 3. Learning contexts in Additive Manufacturing

## 3.1 Introduction

AM is one of the most promising and rapidly growing domains in manufacturing and engineering. The qualifications are evolving beyond technical competences and including some other types of skills, classified and discussed in more detail in WP2. Moreover, the analysis of existing education/training programs in AM reveals that most of them have not only been focused on a single learning context but rather consists of a combination of learning contexts. It is now being expanded into various fields. Therefore, AM is considered a multi-disciplinary field that should be appropriately treated in education and training programs, without forgetting the underlying roots of mechanical and material engineering.

Despite the strong industrial growth, AM education is currently strongly underrepresented in academia, being regarded as a minor subject in engineering curricula. Most universities approach AM with introductory classes and applied workshops to demonstrate the AM capabilities in manufacturing and design freedom.

An example for a well-developed course in AM, is the teaching approach at the Massachusetts Institute of Technology (MIT) for engineering students which differs from that for trainees in industry: For engineering students in the last years of undergraduate and upper graduate levels, the AM training is a triangle pedagogic context (the tree basic learning tools) consisting of classroom sessions, a series of laboratory practices and real case projects. The course begins with the lectures to build a base of comprehension of AM and its related processes. After the introduction, the lectures and laboratory sessions enable the students to experience both learning and application enabling students to experience concurrently learning and practicing. For instance, Fused Deposition Modelling (FDM) is being taught in the class and teams of students are being assigned practices related to the process, including pre-processing (working with some software for part design), printing (employing and observing printing machine functionality), post-processing, and inspection. The next step is an individual project assignment. Each student will be assigned to design and/or assemble a part with the purpose of giving him/her hands-on experience in dealing with challenges in constraints and attributes of the chosen AM process. This problem-centre method enables students to become proactive and learn how to investigate problems, which competences are necessary to solve them, and learn how to investigate problems highlighting the competencies which are necessary. After that, based on their understanding as well as available resources, students will be able to select the most appropriate AM process to complete the assignment. Students face problems which exist in reality, which will enhance their knowledge and skills. It removes the shortfalls of some conventional methods being focused on giving students specific information and asking them to do an assignment based on that given information.

Another example can be found at the Department of Mechanical Engineering of Politecnico di Milano where both Master of Science (MSc) level courses and professional training is offered. Two examples of MSc courses on AM include an Additive Manufacturing course delivered to different streams (Mechanical Engineering, Automation Engineering, Management Engineering, Design) (4) and the Additive Manufacturing for Space and Aerospace course for Mechanical and Management Engineering students, which is also open to PhD students (5). These courses are based on a mix of lectures, discussion of case studies, testimonials from industry, in-class exercises, laboratory activities as well as training on the computer, by design, specific programs dedicated to AM etc. Laboratory activities are conducted to allow students to develop hands-on knowledge on specific AM problems and their virtual representation.

Researchers and faculties of Politecnico di Milano are also involved in different training programmes for AM delivered to professionals. Some examples include: 1) Master Additive Manufacturing, Milan, organized by MIP Graduate School of Business – Management Academy, Politecnico di Milano, 2) Metal Additive Manufacturing - Scenario Research and Industrial Experience, organized by the International Centre for Mechanical Sciences, Università di Udine, 3) Master Bosch Industry 4.0, organized by Cefriel, Politecnico di Milano for Bosch Italia, 4) Master Progetto Formativo Additive Manufacturing Advanced, organized by Confindustria Firenze Formazione for Baker Hughes, a GE Company, 5) Master Additive Manufacturing, organized by Rina Consulting. These courses are based on a mix of lectures, laboratories visits and laboratory activities depending on the background and expertise level of the trainees. Examples of learning contexts and training tools related to these courses are discussed in the following sections.

In the context of the SAM project, as "real-case" scenarios, pilot certified qualification courses offered by the EWF (a main partner in the SAM project) are re-developed or developed. Which qualification will be developed will be selected from the various surveys that will be sent out to industry, training centres and workforce twice a year. From these, the qualifications that seem to be in demand the most; will be selected to be piloted by the different partners under real-case conditions. Hence, partners are advised to follow the structure, competence units and detailed knowledge as closely as possible.

In the 1st stage piloting, three CU´s were focused on:

## 3.2 Opportunities in time of COVID

The coronavirus disease (Covid-19) epidemic has impacted negatively across the globe. In the area of education, this emergency has resulted in the widespread suspension of face-to-face operations at educational institutions in over 190 countries to limit the virus's spread and reduce its effects. Businesses, cannot afford to put capability development on hold. Companies and training centres cannot just halt crucial workplace learning, even as they move quickly to put employee safety first, whether it's reskilling at the business unit level or a company-wide aspirational transformation.

Before Covid-19, digital and virtual learning programs were on the rise, and we are now seeing a significant increase in such learning programs, which many younger trainees enjoy. It could be said that the improved learning abilities that emerged from this epidemic phase may prove to have a favourable long-term effect. The best-practice activities, spanning from the urgent and tactical to the strategic, can help workplace learning programs sustain momentum and benefits while also laying a new basis for effective virtual learning. Establishing a learning-response team, safeguarding the trainees in in-person programs, supporting digital learning, experimenting with alternative digital tactics, and practicing and preparing for diverse outcomes are all examples of these actions.

Simplify. Covid-19 created innovation challenges for both students and trainers who had to adapt training practices to avoid human proximity. Trainers are now experimenting more with virtual learning and adopting new technology such as augmented and virtual reality environments to address this. As an example, it could be mentioned that the manufacturing training is best when it is hands-on, so it will be vital for training providers to discover innovative ways to maintain the same level of teaching, even in the face of the crisis. As a result, manufacturing has become increasingly sophisticated and digital as organizations adopt the technologies (see Virtual Reality Market Share & Trends Report, 2021-2028 (grandviewresearch.com) and The Impact and Potential of Virtual Reality Training in High-Consequence Industries (trainingmag.com)), they need to stay current. This is evidenced by the rise of Industry 4.0 and the Industrial Internet of Things, or IoT.

Certain trends have been noted. Indeed, aside from academics, educational programs, and assessment, maintaining trainees' motivation has emerged as a critical need during the pandemic period. Also upskilling and reskilling must begin immediately in order for businesses to be in the best possible position moving forward. Learning Management

Systems (LMS) make it easier to connect with trainees remotely and at any time by hosting learning content online. They do not, however, always give an assessment zone for example Moodle is an online learning platform where MCQ exams can be taken and scored. They may offer quizzes and auto-grading, but they fall short when it comes to skills and competency. As mentioned above even if the online and blended delivery tools for learning are not new, the Covid-19 pandemic brought them to the forefront. Re-skilling and up-skilling have also become critical for people who have just lost their jobs. Flexible, easily consumable, and industry-relevant courses are in high demand.

Finally, this year, micro-credentials have become a popular choice. These bite-sized course kknown as micro-learning can be constructed by breaking down a unit of competency and can be completely approved and endorsed by a professional organization. This approach of learning appeals to students because it allows them to focus on and gain the specific skill they desire. This helps learners to upgrade their skills and remain current in fast changing industry. Micro learning is predicted to stay in high demand as a result of these factors.

Concluding future students are looking for Flexible, learning, in the flow of work learning and less expensive options that are both flexible and cheap. : Flexible, learning, in the flow of work learning example, part-time students made up 81% of Australia's 4.2 million VET students last year. Course learner's expectations have changed and learner preferences include on-line learning, face-to-face or blended (define blended learning). Tech is the future and online delivery is a must. Online delivery makes assessment digital, portable, flexible and easy to adapt to the assessment conditions, in general trainees/students can be anywhere, this includes the classroom, library or workplace. Finally, it is important to mention several funding opportunities offered recently with the purpose of enhancing the digitalization of the organizations and companies by updating the existing technologies and offered incentives to higher education.

## 3.3 Classroom

In a survey done as part of the SAM deliverable WP 4.3, 5.7,1 % of the survey participants stated that education in AM is taking place in an educational centre. Today, many universities offer part time and full time taught Masters in AM over two semesters. These often include group projects, individual projects and a final thesis. Master studies in AM that mostly last for two semesters which can be taken full-time or part-time. The studies are mostly divided in taught modules, group projects, individual projects, and/or the final thesis.

**Taught modules** topics are delivered in classroom style teaching in the form of lectures and tutorials. The number of contact hours depends largely on the topic of the module and varies throughout the universities. Guidelines on the hours can be found in documents provided by EWF or CLLAIM (see section 4). The assessment of learning outcomes will be done in the form of written examinations, case studies, essays, presentations, and tests. Most universities offering degrees or masters education have AM machines in their teaching laboratories.

In-group **projects**, students work together to solve industrial problems provided by the course director. The project applies technical knowledge and provides training in teamwork and the opportunity to develop non-technical aspects of the taught program. The projects are often supported by external organizations and pose real-life scenarios.

The **individual projects** will be also selected with the course director. The student can demonstrate independent research and thinking.

The multi-disciplinary aspects involved in AM lead to a mixture of training on theoretical aspects and practical/hand-on activities. Classroom training for MSc students is aimed at introducing the AM processes and their applications, discussing their technical and business-oriented implications for designers, engineers, "makers" and other possible users of this advanced manufacturing technology.

As an example, the topics covered in classroom training of the MSc Additive Manufacturing course held at Politecnico di Milano are:

- **Introduction**. Layer-by-layer principles. Benefits and limitation of AM. Historical development of AM technology. Generalized AM process chain. Materials and industrial applications: rapid prototyping, rapid tooling, direct digital manufacturing. Process selection, market availability and trends, business opportunities.
- **AM technology: Polymers.** Description and modelling of the main AM processes for polymers. Machines, software issues, post-processing, design for polymer AM.
- **AM technology**: **Metals**. Description and modelling of the main AM processes for metals. Machines, software issues, post-processing, design for Metal AM.
- **AM product verification**. The need for precision metrology. Dimensional and geometrical metrology for AM: limits of tactile and optical measuring systems; volume-based measuring systems: 3D X-ray computed tomography. Surface topography measurement (tactile, optical, or other and analysis methods).
- **AM process monitoring**. The need for precision processing. In-line monitoring for AM: process variables measurement, monitoring approaches, sensor, and data fusion.

Another example for classroom teaching can be seen in the Additive Manufacturing for Space and Aerospace course held at Politecnico di Milano. Classroom training is aimed at a providing deep understanding of all current AM technologies used in high-end industrial sectors. Each manufacturing process for metals (conventional and non-conventional), polymers, composite materials, ceramics, and glass, living cells/human organs is described in detail. Every process is analysed in terms of main applications and the process which offers ideal performances as well as all associated advantages and drawbacks.

The course subsequently addresses all currently open technical challenges. For example, design aspects and associated design rules for AM, manufacturing challenges which start with raw material procurement and control (powder-screening methods, procurement specification and verification requirements). For the manufacturing process itself, process stability and its monitoring/controlling, most universities offering degrees or masters education have AM machines in their teaching laboratories. Product play the major role. Moreover, space qualification and validation routes are addressed. Lastly, standardization is presented in order to facilitate the market uptake of 3D printing and promote its innovation potential to industrial competitiveness. Lastly, the course provides an outlook on the future developments related to AM, including the 4D printing as well as industry 4.0 developments.

**Virtual classes** have recently become a necessity due to the limitations imposed by the spread of coronavirus. This has already forced existing courses to temporarily be offered remotely. It is expected that Covid-19 will have a massive impact on future training. Although, training methods have been partially adapted to remote classroom platforms, the contents have been kept the same. However, it is interesting to point out that this contextual situation also opened discussions and the understanding of the role of AM technologies when acing emergency situations and a rapid demand for products commonly produced by other manufacturing methods. Including these discussions in training courses on AM may have the potential to increase trainees' awareness about the strategic role played by AM at national and international level.

Additive Manufacturing teachings are sporadically being implemented in classrooms of both high-school students and undergraduate engineers. At the engineers' degree level, the AM education takes the form of certain classes as a part of a broader curriculum program. As an example, Granta Design has developed resources for undergraduate and postgraduate teaching which are focused on traditional materials engineering courses but includes AM as a growing area for new resources. The ready-made PowerPoint lecture units and associated exercise booklets are made available in Teaching Resources HUB https://grantadesign.com/education/teachingresources/.

Customized materials property charts can be created to illustrate the particular point, and copied into PowerPoint, or saved as a project file and opened within the software so that you can annotate the chart in real time during your lecture. The GRANTA EduPack software is also used as the basis for short, hands-on student exercises during classroom sessions, or as 'homework'. The EduPack teaching resources provide such exercises. Students can investigate materials and create reports or posters to prove their learning. EduPack software is available in most universities across Europe teaching materials engineering through campus wide licences. Table 2 provides an overview of the teaching unit content integrated in the EduPack.

Table1. Summary of the teaching unit contents supporting the learning of AM technologies principles.

| AM Principle | Content Unit |
|---|---|
| Generic Principles of the AM Technologies | Layering Nature |
| | Forming processes (e.g. melting, sintering) |
| | Post-Processing |
| Design for AM | Description of the AM Freeform nature vs conventional subtractive vs other forming manufacturing |
| | AM Buildability Restrictions |
| | AM Manufacturability and design alternations |
| | Topology Optimization and Generative Design enabled with AM |
| AM in Series Production | Economies of scale vs mass customization |
| | AM - added value for production |
| | Additive Manufacturing for the Product development phases and final production phases |

An internet search for AM training courses (Master and Bachelor) for different organizations across Europe, as well as industrial training courses showed the coverage of the following topics, depending on focus areas:

- AM Processes for Metals
- AM Processes for Polymers
- Engineering and Scientific Principles of AM
- AM Materials (Plastic/Metal)
- Build strategies
- Manufacturing Quality (defects, standards, procedures, statistical control)

•Inspection of quality features

•AM Metallurgy (metallurgical characteristics / Near-net shape manufacturing

•Post-processing in AM – Heat treatment principles

•Design for AM /CAD

•Finite Element Analysis

•Process simulation / Modelling in AM

•Software in AM

•Data systems in AM

•Factory Implementation (Industry 4.0)

•AM Systems Design

•Automation and Robotics

•Critical thinking and problem solving

•Cross functional teaming and ideation techniques for seeding creativity

## 3.4 On-line learning

A survey undertaken in WP 4.3 of the SAM project, showed that online education accounted for 27,4 %. However, as mentioned before in section 2.2, a constant growth is expected because of the CoVid 19 spread and the digitalization of education and training.

Online learning is commonly referred to as computer-enhanced learning, computer-based learning, interactive technology and distance learning. It can be divided into different areas: university online courses for Master students, free access online courses, online platforms such as MOOC, and short courses for the industry. Free-of-charge courses provide a lower level of information and are more tailored to the general public. Master courses charging a tuition fee provide in-depth knowledge. Most universities which offer Master courses in AM, also offer programs designed to be undertaken online. However, courses that will be taken online may still require on-site training in laboratories. The courses are divided into different modules and the same topics will be covered as has been shown for classroom teaching. Depending on the type of online learning, different learning approaches will be applied. Fact-based learning is mostly related to introductions and free-of-charge courses, whereas project, inquiry or problem-based learning can be more applied to the teaching of Master students.

As mentioned before, an institution that provides online learning, the MIT, stands out: video lectures are given and students learn from educational and industry experts via interviews. Manufactured parts are assessed online, and the use of cutting-edge software is foreseen in the future. In order to communicate, a browser-based edX platform is used which includes multimedia, presentations, 3-dimensional part data and interactive and quantitative tools. CAD designs can be saved in a cloud and cost models can be readily accessed. Furthermore, the online accessibility allows for an online knowledge base with supplemental content of AM topics expanding the range of taught topics. The communication between students and peers can take place via an online discussion panel. Further to the MIT

University online training platform, several other online training platforms associated with well-known universities such as UDEMY, Alison, Coursera and EDX offers a range of non-specialist /specialist training courses. Which quality these courses relate to has not been part of the study. Furthermore, the European Union provides free online courses covering the basic topics to provide a wider understanding of AM (see chapter 5 – European Activities). Those people interested in AM can also access knowledge via online handbooks, webinars (often provided by AM vendors) and blog posts.

## 3.5 In-use On-line learning platforms

### 3.5.1 3DExperience by Dassault Systems

The 3DExperience is an overall business platform that is database-oriented and allows a collaboration between different shareholders who have been granted access. The platform is focused on various professional roles for different technology sectors and depending on the selected and/or purchased role, in-apps can be used to guide through the user through a process.

In the case of AM, it covers the whole process chain and can be applied throughout the learning process. The platform is mainly aimed at engineers and designers but also at students to provide a hands-on learning platform that poses a step-to-step guide through the AM process chain. The platform is accessible for private purposes, companies or public cloud. Hence, one provider, such as a university, can grant access to different shareholders (students) to work individually or in teams on AM projects. Theoretically, a student group can apply a real-life case study by considering different roles in a company. The platform is based on a PLM (Enovia), so users, permissions and version control management are quite easy. The initial configuration is similar to creating a team in Teams.

Four different applications can be chosen: CATIA to create a functional generative design, Delmia to simulate the build planning process during Powder Bed Fusion, Simulia to carry out AM manufacturing simulations and CATIA2 to create virtual to real shape morphologies. Depending on what is needed by the students, they chose an application or go step-by-step through the process chain. Going through the whole process chain helps the student to work with AM in an overall approach. Within CATIA the design and optimisation of AM parts can be studied, whereas Delmia is a more process-oriented tool focusing on the knowledge of the build process. Simulia and CATIA 2 focus on the process variables and their influence on the part within the process but also the influence of post-processing strategies. The single apps simulate a real-life process chain, and the 3D experience software allows the students to work in a real-life environment that is also used in industry today. The platform is used to roll out the Project Based Learning (PBL) methodology. People can use different tools and methodologies within the platform to develop new AM products and get familiar with different software programs.

### 3.5.2 Ansys Learning Hub

Ansys offers a web based online learning hub with training resources to tackle current projects and develop opportunities to enhance the AM skills, particularly for the AM design and simulation engineer. It is a subscription-based service, with access to a wealth of resources including classroom courses scheduled globally, virtual courses in all time zones, self-paced video courses, learning paths to guide the course selection, dedicated learning rooms for questions and discussion, and detailed training materials. Specifically, the current courses for developing AM skills through Ansys software are:

- **Introduction to Ansys Additive Prep.** The target audience are engineers, designers and machine operators working with metal printing machines. The teaching methods consists of lectures and computer practical sessions to validate acquired knowledge. "Ansys Additive Prep" teaches the workflow inside Additive Prep software, from part import to export of build files containing all necessary information for the printing machine and/or for the printing simulation. In this course, the trainee learns how to find the optimized orientation to print a part, on how to automatically detect the regions which need support; the way to create and define the supports parameters are presented in the lecture file. Trainees learn where to input the printing machine parameters for build file generation. Finally, the course presents the additive manufacturing simulation's next step: export build file and use it in Workbench Additive or in Additive Print products. This course teaches where to define the supports parameters, how to define the machine parameters. A training certificate is provided to all attendees who complete the course.

- **Introduction to Ansys Additive Print**: In this course the trainees learn about: the DMLS process, the calibration process, solve advanced thermal analysis problems, predict distortion, differentiate the strain mode options, generate the geometry-based support, chose the parts build position, chose the scan pattern, visualise and evaluate the print results. The target audience are Engineers, Designers and Machine operators working with metal printing machines. The teaching method includes lectures and computer practical sessions to validate acquired knowledge. A training certificate is provided to all attendees who complete the course.

### 3.5.3 Granta Education Hub

Granta Design develops teaching and student resources as well as materials databases and educational software using sophisticated tools to support the teaching of materials selection, design, and sustainability. The approx. 350 teacher and student resources are made available for free via the Granta Education Hub website on https://grantadesign.com/education/teachingresources.

The types of resources include presentations, exercises, case studies, papers, video tutorials. The lecture unit "Manufacturing" covers the fundamentals of materials science and related processes which should form the basis for any AM training. The teaching units consist of: Materials and Shape, Material selection, Manufacturing process and cost, etc. The teaching resources are translated into 8 languages.

## 3.6 Laboratories and Workshops

An important aspect of training in the field of AM are hands-on activities and lab visits. The former can be organized and implemented in different ways. As an example, in the framework of the Master Bosch Industry 4.0, organized by Cefriel and Politecnico di Milano for Bosch Italia, the trainees have the possibility to experience all the steps from the design of the part to the slicing, preparation of the g-code and final printing. This makes the trainees aware of the practical issues related to 3D printing and its industrial potential. It also allows them to put in practise the principles and concepts learned during the course. At Politecnico di Milano, Department of Mechanical Engineering, a classroom equipped with several 3D printers for polymers that can be used directly by the students is made available to this aim.

Lab visits are important too, as they allow trainees to see and touch real parts, industrial systems, and research prototypes. Students can learn about ongoing research and development projects to get a better feeling for of the current state-of-the-art but also deal with open issues and innovative solutions not yet on the market.

Within the educational and academic world, AM has a strong presence in the laboratory and workshop areas. With the uptake of the desktop 3D Printer, AM equipment was made affordable for small entities to be owned and operated. This generates two major advantages for AM education.

First, laboratories with other than AM research activities, can leverage the manufacturing capacity of their desktop printers and print parts for their research activities. Secondly, real-time demonstrations of how 3D printed parts are considered the most valuable and effective way to introduce AM as a new technology. This out-of-the-classroom and live alternative introduction aims to urge students to actively get involved and engage in learning efforts for the AM technologies. AM workshop activities usually aim to educate by demonstrating:

- AM part forming
- AM machine operations (feedstock e.g. powder loading and unloading)
- AM post-processing processes

## 3.7 AM Certifications and Diplomas

An AM certification is currently the most popular official competence validation in the European industry. The institutions that provide AM certifications are either AM training centres (certified or un-certified by for example EWF) that also provide relevant training for the participant to obtain the required AM understanding or assessment centres that validate the examinee's AM competences.

In the academic world AM education does not have a distinct certification among the major engineering degrees. It comes as a minor or a specialization within the major disciplines and engineering diplomas. The engineering student can either select a series of available AM courses in their faculty, to enrich their understanding in the AM processes or continue its postgraduate studies with a Master of Science or PhD in AM. Additional AM certifications that are provided within universities are professional Masters of Engineering or graduate credit certificates. This type of AM education and certification are brief (one-year) and commonly have a digitalized character such as online courses.

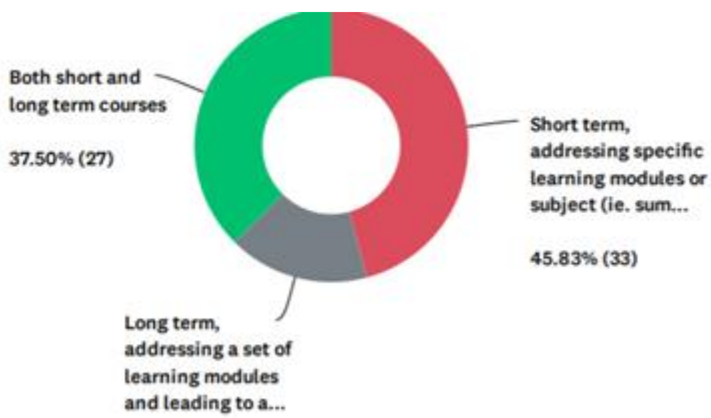


Figure 3: Length of the AM courses

The content of all the AM certifications has the tendency to be highly specialized and targeted to thematic axes that range from Design for metal AM to AM machine operations and AM powder handling.

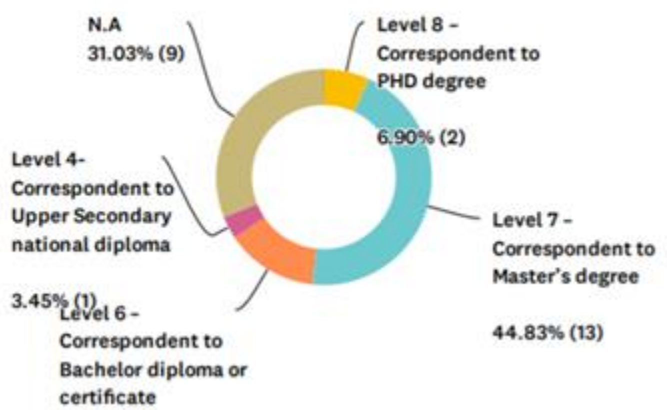


Figure 4: Targeted EQF Level

## 3.8 In-company training

Many companies within the AM field offer short courses on AM topics. As short courses usually aim at a wider audience, the topics often include:

- Feasibility of part designs
- Implementing AM
- AM processes
- Materials in AM
- Cost calculation of AM Parts
- Part quality (properties and tolerances).

Short courses are often provided by service or technology providers. Furthermore, engineers will receive special training for process validation, maintenance, troubleshooting, software, cost estimation, health, and safety, as well as planning and executing 3D scanning and printing. A course example from TUV Sud can be seen here: https://www.tuvsud.com/de-de/store/academy/technical-trainings/additive-manufacturing

A training program has been developed by the European Welding Federation https://www.ewf.be/additive-manufacturing, in which different contexts are taught depending on different job profiles. These profiles are classified as follows:

- Direct Energy Deposition - DED (wire plus arc) Operator
- DED (laser) Operator
- Laser Powder Bed Fusion Operator
- DED (wire plus arc) Engineer
- DED (laser) Engineer

- LPBF Engineer
- Designer
- Inspector

Another provider of an AM training program is PM Life https://www.pmlifetraining.com/about/about-pm-life which has been developed by the European Powder Metallurgy Association. The program is aimed at developing the future of Powder Metallurgy. People can choose and select different modules or can attend a full programme. The courses last one week and take place in different locations around Europe. An internship in a factory or university is proposed at the end (three weeks). Finally, a certificate is awarded. The following topics are covered.

- Press and Sinter
- AM
- Powder and Hard Materials

As far as courses for professionals are concerned, both training internally and externally is carried out. Most of the examples mentioned above (such as Master in AM (Milan); Università di Udine; Master in AM (Rina Consulting) and AM Engineer training (MTC)) are involved in externally training the professionals in Universities or training organisations (such as the EWF). On the other hand, some external organisations deliver internal courses to industry (such as Progetto Formativo AM Advanced (Confindustria Firenze Formazione for Baker Hughes, a GE Company). Within the framework of the Master Bosch Industry 4.0, organized by Cefriel, Politecnico di Milano for Bosch Italia, some training modules on AM were held in the Company, whereas other modules were held in the University. In particular, providing part of the course externally eases the inclusion of lab visits, hands-on sessions internally and direct experience with state-of-the-art research in the field carried out by the Institute. Internal training on the other hand has the potential to customize training content with respect to the needs of the company itself. In-house training may be supplied by machines vendors who provide on-site specific machine or technology training.

## 3.9 Blended learning

The definition of blended learning, which is the mixture of learning techniques, has been investigated over the years and it was found that in a broader sense, all above mentioned learning contexts can be (one way or another) regarded as blended learning techniques. Blended learning is the interaction between face-to-face and online teaching. Hence, online teaching (§3.4) could be mixed with lab work or workshops (§3.6). The teacher is free to choose which method, combination and their ratio might be appropriate to tailor the needs of the learner´s group. Furthermore, blended learning aids a rapid adaptation of trends in terms of learning styles but also quick integration of new online learning tools. This is regarded as a real advantage especially in an age in which digitalization progresses quickly and the professor needs to stay on top of the developments.

There are several teaching methods that can be employed in blended learning:

- Face-to-face (traditional student-teacher)
- Rotation (students go from one station/activity to the next)
- Flex (students control their learning path – professor acts as mentor)
- Gamification (including game play elements: for example: students compete and jump from level to level)
- Online lab (entirely online learning to deepen knowledge)
- Self-blend (engage the interested students in white papers, blogs, video tutorials etc.)

- Online learners (self-directed learning while the professor, trainer or teacher acts via for example video chat).

## 3.9 Overview of the Presented Learning Contexts

As has been shown in subsection 3.1 until 3.7, different learning contexts are currently provided for AM training. The type of learning context depends on the specific course details. Table 2 provides a summary of recommendations with constraints and their potential assessments are shown.

Table 2: The summary of recommendations in applying learning contexts in AM training

| Type of Learning contexts | Advantages | Constraints | Recommendations for being applied in AM training | Assessment |
|---|---|---|---|---|
| On-line learning | Easily accessible | All virtual – no hands-on<br><br>Additional equipment could be necessary (e.g. Oculus Rift for VR) | For the future combined with in-company or teaching facility approach. | On-line tests; multiple choice; essay. Feedback exercises (Flipped classroom) |
| Classroom / Lecturing | Established method | Fact-based learning | Needs to be combined with hands-on teaching experience. | Multiple choice; essay; problem based. |
| Laboratory | Hands-on learning; needs to be combined with classroom | Equipment in laboratory | Needs to be combined with a lecturing etc. Activity. | Fulfilment of lab study; problem based; group work; practical. |
| In company training | Project-based learning or problem-based learning. | Often focused on single industry or process which limits an overall approach in AM. | Should be carried out with an on-line or classroom activity to give a full overview of the topics. | Practical; |
| Blended learning | Could reach everyone; allows quick adaptation for new tools and learning trends; low cost; adaptation to learners needs. | Learner characteristics need to be examined beforehand to cater for the needs. Learning outcomes should be defined beforehand. | Is a good opportunity to deal with theoretical content and practical approaches (tutorials /machines). | Online testing; Lab studies; group work; multiple choice; depending on how blended learning is integrated. |

# 4. Training tools in Additive Manufacturing

## 4.1 Teaching Factory Paradigm

The Teaching Factory (TF) paradigm utilizes education and training from the individual needs of both the academia and the industry side. The direct communication of university engineers and industrial stakeholders is established to perform a collaborative task (6) These two sides are tackling a shared problem of engineering while having separate end-goals, as presented in Table 3.

Table 3: Objectives of Teaching Factory

| Objectives of Academia | Objectives of Industrial Partners |
|---|---|
| **Technical Expertise** | New solutions |
| **Practise Knowledge** | Decision support |
| **Real-life imposed problems** | Out-of-the-box approaches |
| **Proof-of-concepts** | Task Outsourcing |

The different goals can be achieved by a symbiotic relationship between academia and industry in which the teaching factory acts as the channel of communication and a catalytic factor.

Since TF tools are mostly digital, the barriers of distance are eliminated. This model can be applied to a global level within the university and the industrial shop floor being separated.

To do so the TF approach acts as a two-way channel: it can be implemented from the factory towards the classroom and from the laboratory towards the production floor. The three main applications when it comes to Teaching Factory are:

1. Academic learning
2. Professional learning
3. Societal learning

The AM TF is to be used as a training tool with a purpose of exchanging expertise from the industry towards the academia and vice versa (7). The objectives of the AM TF are:

a. Provide technical knowledge and specialized education to engineering students to in order to better educate and upskill the future AM workforce.
b. Improve the technology readiness of new AM related technologies and accelerate the adoption of AM production in the industrial sectors.

The implementation process of the AM TF requires two parties. The first one comes from the industrial world. This party of the AM TF model brings a real-life production problem to be resolved or a new development to be carried out. The industrial party also has the AM equipment and the actual production of the AM component.

The second party consists of members from the academia community. This side of the party provides the analytical solution for the problem to be talked or the research for the needed developments.

With the completion of the AM TF both parties benefit as the industrial side will have advanced its production and the academic side will have gained valuable insight and experience.

## 4.2 Serious games

**Serious games** that is, (digital) games used for purposes other than mere entertainment. The starting point is the serious games concept itself, and what the actually means. Further, serious games allow learners to experience situations that are impossible in the real world for reasons of safety, cost, time, etc., but they are also claimed to have positive impacts on the players' development of a number of different skills. Subsequently, some possible positive (and negative) impacts of serious games are discussed. Further, some of the markets such games are used in are considered here, including, military games, government games, educational games, corporate games, and healthcare games (see Serious Games: An Overview (diva-portal.org)). They describe the use of game engines for non-game related applications. Meaning, that games will be used for the training, advertising, simulation, and education. The power of games to captivate the user is used to acquire new knowledge and skills. A growing number of schools is offering game arts degrees such as Bachelor and Master of Fine Arts and/or Bachelor and Master of Science depending on the topics that are chosen. Susi et al. (8) describes serious games as a fun way to learn about serious issues in manufacturing. For example, audio and visual instructions can easily be applied to guide a user through assembling a new product for use or providing routine maintenance or even emergency repair. Many applications currently involve pre-procedure routines in the medical environment, simulations to manage phobias and teaching math problems. Entertainment has been proven to be an effective way to share and transfer knowledge.

In terms of AM teaching, a multiplayer mode could be developed to allow different learning groups take on different roles in the AM process with for example interactive platforms. Another example in which serious games have been applied successfully is the immediate use of real-time engine application which has been created by taking CAD data, reformatting, and reducing it (9). Real-time visualization can help for example a process engineer to understand the AM machines and environment better.

A recent example of an AM "serious" game is a video game dedicated to the discovery of Metal Additive Manufacturing. It is called "AddUp Adventure" and has been launched in 2019 by AddUp. The game acts like the "SIMS" and is set in an 3D environment and exploits dialogues with non-players, environmental narration, non-linear exploration phases, collection of objects, mini-games and fact-based learning. It is assumed that the AddUp Adventure helps learner's involvement and helps to train people with a non-technical profile.

## 4.3 Augmented reality

AM programs combining augmented reality/virtual reality (AR/VR) and AM can currently only be found in the United States of America. The University of Arizona offers an 8-course certificate program, online or in-class which will lead to a minor in AM (https://ami.arizona.edu/courses). Topics will include:

- AM process simulation
- Physics based modelling using Unity3D game engine
- Evaluation of trainees based on time, accuracy, and human factors
- Cognitive perception supported by immersive experience using VR/AR equipment

- Visualization and haptic feedback
- Digital twins and machine learning for process modelling and control
- Cyber-physical security and infrastructure

A learning resource for augmented reality and 3D printing has been developed by 3D Bear. This company works on remote learning resources combining immersive technologies and inspiring pedagogic content for the best learning results. Augmented reality ("AR"), virtual reality ("VR"), 360-photos, scanning & 3D printing. Professional development, implementation, and workshops.

https://www.3dbear.io/

The paper "Augmented Reality Interfaces for Additive Manufacturing" (10) explores potential use cases for using augmented reality (AR) as a tool to operate industrial machines. As a baseline they use an additive manufacturing system, more commonly known as a 3D Printer. They implement novel augmented interfaces and controls using readily available open-source frameworks and low-cost hardware. Their results show that the technology enables richer and more intuitive printer control and performance monitoring than currently available on the market. Therefore, there is a great deal of potential for these types of technologies in future digital factories.

Other experiences related to Virtual reality are mentioned in "A Virtual Reality Application for Additive Manufacturing Process Training" (2015). This paper presents an extensible software application that simulates an AM process in a Virtual Reality (VR) environment. The application parses machine component movements and printed segment attributes from G-code files exported from the MakerBot® Computer Aided Manufacturing (CAM) software. Position, speed, and type of movement are used to simulate the physical machine movements. A print "segment" is created at the start and end positions of a print movement. Color-coding segment attributes and modifying their size and shape establishes a visual relationship between terminology for a print setting and its representation in the virtual environment. This visual relationship between printed segments and print settings makes it easier to learn the 3D printing process and associated terminology. Novice and expert users can modify print settings in the virtual environment before and after printing a prototype. Identifying and fixing a mistake in the virtual environment reduces the time and cost to print a part with the desired quality.

## 4.4 Project-based Tools

Inductive teaching methods include inquiry-based learning, problem-based learning (PBL), project-based learning (PjBL), case-based teaching, and just-in-time teaching.

The problems/projects are designed to be representative of authentic problems, which have been shown to motivate students, maintain their interest, and actively engage them in learning. PBL learning approaches have been found to improve the development of critical thinking and problem-solving, and to enhance understanding of critical engineering concepts.

The central principle of the PBL approach is that students' fulfilment of learning objectives is accomplished through the solution of an open-ended problems, rather than through a deductive presentation of information. The problem, which is carefully designed to be authentic and reflective of professional practice, serves as the motivation for learning the content. Students work in small groups to solve the problem by first identifying what they already know, what they need to know, and how and where to access the information that will assist them in solving the problem. The problems are used as an opportunity for students to acquire the desired knowledge while simultaneously enhancing their problem-solving skills and their competency for self-directed learning. Simply providing students with an open-ended problem is not considered true PBL. The instructor must guide the learning process while also leading students through reflection and debriefing at the conclusion of the experience. An example for an AM course could be:

- Explain the capabilities, limitations, and basic principles of alternative AM technologies.
- Evaluate and select appropriate AM technologies for specific design-manufacturing applications.
- Explain the fundamental causes of errors and irregularities in AM parts.
- Apply AM techniques to a challenging design and manufacturing application.
- Identify, explain, and prioritize some of the important research challenges in AM.

An important aspect of training in the field of AM regards hands-on activities. In this field, teamwork projects have various possible benefits. On the one hand, they allow the trainees to directly experience the several potentials of the AM technologies. In addition, they consolidate the achievement of expected learning outcomes via hands-on sessions and working with real data and products. Moreover, they foster team working skills in multicultural and multidisciplinary environments, since AM courses commonly include trainees with different backgrounds.

The following example regards a laboratory and teamwork activity in the framework of the Additive Manufacturing for Space and Aerospace course held at Politecnico di Milano. The students of the course were asked to redesign for AM real space component, the support that connects the reaction wheels for attitude control of the ION Cubesat Carrier, a new version of a small spacecraft originally designed by D-Orbit, an Italian start-up (https://www.dorbit.space/) for last mile delivery and positioning of CubeSat satellites. For this version of the spacecraft, D-Orbit is directly working with ESA, and their technology will also be employed for ESA's Clean Space initiative on in-orbit servicing and active debris removal.

All teams were asked to minimize the weight of their redesigned support, comply with the mechanical requirements of the structure (static assessment and modal analysis) and optimize the manufacturability. The winning team composed by four students won the competition by presenting a design that allows them to achieve the highest weight reduction (-65% with respect to the original weight of the component) in compliance with all the mechanical and "printability" requirements. At the end of the project, the participants were engaged in a final presentation day.

As another example, in the framework of the MSc Additive Manufacturing course held at Politecnico di Milano, students carry out a teamwork project where they are asked to design for AM and print with Fused Deposition Modelling parts that must comply with imposed functional requirements and maximise some given objective function. Two examples of projects in part years include the production of toy cars that were then tested during a competition among all the teams (cars had to travel the longest distance down from a ramp) or bridges tested in a competition too (bridges had to support the highest weight without collapsing).

All these project activities allow the students to learn new SW tools: for topological optimization, build preparation, processes, simulation, as well as use 3D printers, to apply most of the learned concepts in practise and to experience the actual potentials and limitations of AM methods. The competition has the benefit of strengthening the commitment of students and foster their interest for in training topics.

GRANTA EduPack software is a suitable resource for student carrying out project and problem-based learning as it offers both as a comprehensive information resource and software tools such as materials selection, Eco Audit, and other modelling tools to solve materials-related problems. These projects could be anything from short exercises within an introductory course (examples are provided in the GRANTA EduPack teaching resources) to extensive final-year design projects or even masters-level research projects (using the in-depth data in the EduPack Level 3 database).

## 4.5 Case studies

The inclusion of case studies in the training has been of great importance for both university level courses and courses for professionals. As an example, in the framework of the Additive Manufacturing for Space and Aerospace course held at Politecnico di Milano, real-life case studies (mainly from the space and aerospace domain) are presented once the student is fully aware of all currently available technologies, their benefits and drawback, and the main open challenges. The objective of the course is to provide the student with a current industrial implementation approach of AM on high-quality products. End-to-end design/manufacturing processes of real spacecraft, satellites, rockets, or aircraft parts are shown. Starting with the design/topology optimisation (bionic design), moving to the selection of the ideal AM technology up to the optimisation of the process parameters, the mechanical characterisation (static, fatigue, microstructure, NDI, computer tomography, eddy current, etc.) and the production of a breadboard to be full scale tested and then flown into orbit. Moreover, the course provides case studies and examples of failure investigations on real components.

## 4.6 Lectures by AM Experts

The multi-disciplinary aspects involved in AM typically impose to involve experts in different fields giving lectures on specific topics. This approach has been followed both in MSc courses and courses for professionals. As an example, the MSc Additive Manufacturing course held at Politecnico di Milano foresees lectures of faculties that are experts in different fields (manufacturing processes, quality engineering and data analytics, metrology and measurements, etc.) together with seminars held by invited experts from industry or from other research groups. Seminars are highly appreciated by the students as they allow the trainees to get in contact with industrial viewpoints, real implementation experiences, challenges, and opportunities. Seminars from experts are also effective in showing the current state-of-the-art adoption of AM technologies in nowadays industry and they impact on societal and economic growth aspects.

The Additive Manufacturing for Space and Aerospace course is held at Politecnico di Milano represents a different example, as the course if fully held by Tommaso Ghidini, Head of the European Space Agency (ESA)'s Structures, Mechanisms and Materials Division. In this case, MSc students have the opportunity to get in contact with one of major EU experts in the field who transfers his very applied and practical approach on AM related topics and issues to the trainees. As an example, after successfully completing this course, the student is supposed to be able to:

- Identify trends, technologies and key methodologies related to digital and additive manufacturing for high-value-added products (Applying Knowledge).
- Develop new ideas and solutions in emerging industrial businesses. In fact, Additive manufacturing is one of the more active playgrounds for new solutions, innovative ideas and start-ups. (Applying knowledge and making judgements)
- Interact in a professional, responsible, effective and constructive way in a working environment. The project work will allow all the students to interact in a multi-disciplinary environment. In fact, the project team will mix students in management, mechanical, design, automation and physics engineering (Team-working and communication abilities).

Additionally, in the framework of courses on AM for professionals (at least for engineers and managers), lectures are commonly held by different experts in their specific fields, ranging from material science to laser- and electron beam-based processes, design for AM, quality control and material testing, metrology, simulation, data analytics, life cycle costing, etc. As an example, the LILIAM – Lifelong Learning in Additive Manufacturing - project (https://www.liliam-project.polimi.it/), a team of eight international partners from different EU countries was put together to develop a lifelong training programme for professionals (product and process engineers and managers) combining several different expertise to provide a comprehensive and multi-disciplinary learning path. LILIAM aims to include lectures on the following topics: 1) Materials for additive manufacturing, 2) Additive manufacturing processes, 3) Product design and optimization, 4) Modelling and simulation, 5) Process monitoring and control, 6) Post processing / hybrid processes, 7) Control, qualification and certification, standards and IPRs, 8) Lifecycle assessment, lifecycle costing, 9) End of life and recycling of materials.

## 4.7 Overview of the Presented Learning Tools

As has been shown in subsection 4.1 until 4.6, different learning tools can be applied for AM training. The type of learning tool depends on the specific course characteristics. In table 4, a summary of recommendations as well as constraints and their potential assessments are shown.

Table 4: recommendations in applying learning tools in AM training

| Type of Training tool | Advantages | Constraints | Recommendations for being applied in AM training | Assessment |
|---|---|---|---|---|
| **Teaching Factory** | Hands-on learning experiences. Brings industry closer to academia. Hands-on teaching | Depends heavily on the infrastructure. | Should be used in conjunction with other "traditional" learning activities. | Problem-based; group work; |
| **Serious games** | Problem-solving, Fun, In line with digitalization | No hands-on experience. | Complementary to other teaching activities such as classroom and laboratory. | Practical, interview |
| **Augmented reality** | In-line process learning; | Currently only available for a few processes and variables. No hands-on experience. Virtual. | Should be used in conjunction with other "traditional" learning activities or teaching factory. | Practical, interview |

| | | | | |
|---|---|---|---|---|
| **Project** | Can be carried out along with the training. Students get to see the whole process chain. Equally valuable for all people. Easily adjustable project sizes. | Will have to be developed for the whole course. | Strongly advised as people can learn from learning by doing and applying the 3D printing process chain. | Individual; interview |
| **Case study** | Allows to implement the obtained knowledge. | Depending on case study – hands-on experience might be missing. | | Essay: problem based. |
| **Lecturing** | Easy to get an overview of knowledge from all students. Face-to-face. Easier approachable. | No hands-on experience. Targets mostly students or pupils. | The documentation of the working materials is out there. | Multiple choice, Essay, interview. |
| **Virtual Workshops** | Used in AM simulations, Students get hands on experience at running set simulation exercises and talk to trainers for guidance | Students need to all get to the same level to be able to practice simulations and have access to tools | | Q&A, Practical exercises |

## 5. European AM projects activities supporting AM Learning and Training

**Admire (Alliance for aDditive Manufacturing between Industry and univeRsitiEs)**: Admire was an alliance between AM companies, universities and students that responded to an industrial need: *the qualification of the AM workforce*. A European Metal AM Master degree was developed that is according to level 7 of the European Qualification Framework.
https://admireproject.eu/summary.html

**3D Prism**: 3D Prism has developed a "Massive Open Online Course (MOOC)" which is available for public use. The course covers basic aspects and different AM technologies, materials, process parameters, CAD/CAM tools and maintenance topics. The course is available for everyone online and knowledge will be tested via Quizzes.
https://versal.com/c/jppgwv/3dprism-mooc

**Metals** – MachinE Tool Alliance for Skills. The metal project was concerned with the preparation of skills needed for an AM Operator at EQF level 5. An online course has been developed which provides a curriculum for 3 different sector. Firstly, AM units – covering all aspects of AM processing from design to post-processing. Secondly, Work-process oriented units in which acquiring contracting skills to maintenance skills will be provided. Thirdly, entrepreneurship units in which marketing, leadership and other aspects are covered. Skill examination takes place through an online test from which 80% of the answers need to be correct.

**3DP – Training in 3D Printing to Foster EU Innovation &Creativity**
This European initiative has provided written guidelines on short course topics, trainer guidelines, courseware and case studies in order to successfully improve the skills of students. Furthermore, a 3D printing e-learning platform has been developed which is available in 6 languages.
https://3d-p.eu/

**CLLAIM – Creating Knowledge and Skills in AM** – currently running
CLLAIM is concerned with developing an AM qualification system by establishing a qualification body, different qualifications for different roles, innovative training packages, Recognition of Prior Learning (RPL) models and a pedagogical kit for trainers focused on work-based learning methodologies.
http://cllaimprojectam.eu/

**PAM2 – Precision Additive Metal Manufacturing** – currently running
PAM 2 aims at drastically improving the precision of metal AM processes by tackling the three principles of robustness, predictability and metrology, and by developing CAE methods that empower rather than limit AM design. The project has provided a high amount of research paper resources as it looks at 15 interconnected research projects for Early Stage Researchers. Furthermore, a YouTube series has been developed in order to guide interested people through the topology optimization modelling process in AM.
https://pam2.eu/

**EIT Manufacturing Projects:**
**EIT-AddManu**: EIT-AddManu will develop an online "AM Teaching Factory" in which learning nuggets from teaching AM in higher academic and industrial education will be provided. The Platform shall contain design tools, screening of suitable AM systems and selecting the right material for a product. https://eitmanufacturing.eu/additive-manufacturing-teaching-factory/

**LILIAM**: lifelong learning in Additive Manufacturing – currently running. LILIAM aims to develop a European training qualification for different professional profiles, including specialists, engineers and managers, in the field of Additive Manufacturing. The training modules, which will combine traditional and innovative teaching approaches, are designed by an international network of partners from 8 European countries coordinated by the Department of Mechanical Engineering of Politecnico di Milano. https://www.liliam-project.polimi.it/

## 6. Examples of Learning Contexts and Tools from SAM Partners

In order to give some insight into how learning contexts and tools are integrated into educational training, two examples will be given here.

### 6.1 LORTEK

#### 6.1.1 Introduction

Since 2018, Lortek and Goierri Eskola offer a Master in AM. Lortek is a private technological centre and a member of the Basque Research & Technology Alliance (BRTA). The centre is specialised in joining technologies for materials. Goierri Eskola is a pluralistic and participatory teaching centre that aims at students that have finished the compulsory education in Spain. The master is aimed at mechanical engineering graduates and technical engineers. It is also aimed at graduates in physics and chemical engineering with a license. Furthermore, technicians with a work experience of three years or above will be admitted after careful examination of knowledge (Recognition of Prior Learning (RPL)). The course takes 1165 hrs, is split into twelve modules and lasts one full semester. Additionally, a short course is offered in which no a thesis is not required to be written. Website: https://www.mondragon.edu/cursos/es/tematicas/ingenieria-mecanica-procesos-fabricacion/master-en-fabricacion-aditiva-industrial

#### 6.1.2 Lecturing

Teaching takes place as face-to-face, present teaching and training activities. Each module will be divided into labs and teaching activities to also foster the practical learning abilities. In the different modules, different aspects of AM with a strong focus on practical metal AM will be taught. All the different modules can be seen as competence units which could also be taught individually. The presidential phase takes up 265 hrs.

- M1 – Introduction to AM and economical aspects (PDF)
- M2 – Different technologies in AM (PDF and demonstration)
- M3 – Design considerations, elements, and tools (Software)
- M4 – Product development metal AM: types of materials, processing, and optimization (PDF)
- M5 – Product development polymer AM: types of materials, processing techniques and optimization (PDF)
- M6 – Manufacturing of metal AM products – defects and post-processing (PDF and practical)
- M7 – Manufacturing of polymer AM products – defects and post-processing (PDF and practical)
- M8 – Other materials (PDF)
- M9 – Industrialization of the AM process chain (PDF)
- M10 – Practical activities (Practical Goierri and Lortek)
- M11 – Master thesis

Short courses or competence units are also accessible which aim to enhance the knowledge in a certain area of AM. The following short courses are available:

- AM for casting processes 12 hours
- AM of plastics and composites for professionals 12 hours
- AM of metals for professionals 18 hours
- AM design for professionals 30 hours

### 6.1.3 Case-Studies

During the semester, students have six months to develop a product for which basic requirements such as the product and description of characteristics will be given (project-based learning). The outcome of this project is the redesign of a product which has been looked at all along the process chain towards industrialization. Students will assess economic aspects as well as production and design aspects and furthermore chose technology and material. The outcome is a report of 70/80 pages in which the reason and steps of the product development have been explained. Every year, a new part is chosen. The case study is set for 400 hrs.

Figure 5: Original drone arms to be redesigned

Figure 6: Drone redesigned by students in AM Master course

The full course includes the writing of a master thesis for which 500 hrs have been projected and will last three months. The master project should ideally be developed by the master student in conjunction with the current company that they are working in (focus lies on an RTO or industrial company). This ensures that the proximity to a real-life work environment has been given. The thesis should be carried out in

In order to develop the parts for the project-based learning approach and the master thesis, students are encouraged to use state-of-the-art but also readily available software in order to be acquainted to the software. Software resources include the following (2020):

- GRANTA EduPack material selection SW from GRANTA
- 3DExperince platform
- Specific software for design (SOLIDWORKs, CATIA)
- Topology optimization (Altair INSPIRE)
- FEM simulation (Dassault Systemes ABAQUS)
- Edition (Markforged EIGER, Materialise Magics)

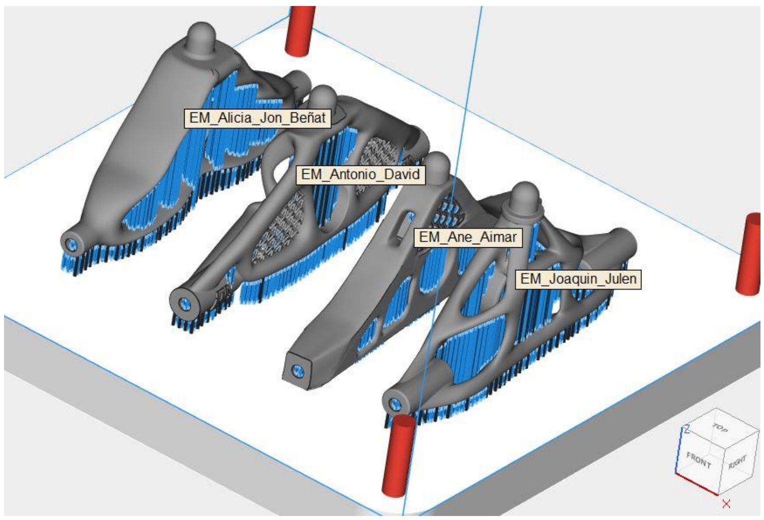


Figure 7: Different skateboard axle designs

### 6.1.4 Serious Games

As the course is aimed at higher education students, serious games are not part of the teaching environment. However, students are encouraged to download the AM-Motion app to test their knowledge in AM.

### 6.1.5 Teaching Factory

Lortek or Goierri Escola are not considered teaching factories. However, the network between industrial partners, research (Lortek) and Goirri (University) and the focus on industrial projects can be considered a teaching factory.

### 6.1.6 Augmented Reality

Augmented Reality is currently not applied during the AM master course. It is considered to implement welding simulators, however currently all practices in welding are carried out in real time.

## 6.2 LZH Laser Akademie GmbH

### 6.2.1 Training course: Specialist for Additive Manufacturing Processes - Metal

LZH Laser Akademie GmbH is one of the leading training centres for applied laser technology in Germany.

Together with SLV Hannover, LZH Laser Akademie was the first institution in Germany to offer a new certified advanced training course for "Specialist for additive manufacturing - Metal" since 2016. The course duration is one week and concludes with an exam.

The advanced training to become a *Specialist for Additive Manufacturing Processes - Metal* addresses a proficiency level from engineer and operator. It is aimed at qualified skilled workers, master craftsmen and technicians who are or will be responsible for the operation of systems for selective laser beam melting and is also recommended for engineers, designers and production managers who wish to obtain basic and comprehensive knowledge of the possible applications in production.

The course imparts comprehensive knowledge of the process principles and process parameters and of the individual steps in the production of components along the process chain.

Further information is available on the German website of LZH Laser Akademie: https://www.lzh-laser-akademie.de/de/seminare/lasermaterialbearbeitung/fachkraft-fuer-additive-fertigungsverfahren-metall/

**Course structure:**

The courses take 40 contact hours incl. assessment and is carried out in full time within five days.

The course takes place as face-to-face training in *classroom* and *laboratory*. The lessons are explained by experts and are divided into theoretical and practical units.

The methodologies used in *classroom* is a combination of *lecturing* supported by presentations and *case studies* to teach the theoretical basis and deepen what has been learnt. The *practical training* takes about half of the course duration (~17,6 hours) and takes place as a combination of *shop floor demonstration* and *practical units*, which build on and deepen the theory units. This procedure enables the participants to try out the theoretically acquired knowledge directly in practice under guidance.

The combination of lecturing, case-study, practical and theoretical training is ideally suited for the transfer of knowledge in: software handling for part and job preparation, machine preparation, starting and monitoring build job, removing and post-processing parts after build job, qualification assurance/part inspection.

**Target knowledge and skills:**

- Knowledge about general AM processes and materials (all materials)
- Detailed knowledge about metal AM processes
- Detailed knowledge about PBF-LB and DED-LB processes (materials, machine systems, software, postprocessing, doing build jobs with complete process chain by attendees)
- By the operator seminar a profound knowledge about metal AM processes is gathered, the training for engineers and advanced operators aims to have a basic knowledge about AM processes and a profound knowledge about metal AM processes as well as experience in conducting a PBF-LB processes (what has to be done, what are occurring errors and what has to be done to correct them), to our point of view, the methods are quite successful to achieve the objective of the seminars)

**Assessment**

The assessment is performed on the 5th training day. With written and oral exams gathered knowledge of all learning contexts is confirmed. With successful participation the certificate "Specialist for additive manufacturing processes - Metal" is obtained.

**Evaluation:**

To close the seminar, the evaluation of the training is done with an anonymous questionnaire.

## 6.3 Educational Software - Granta EduPack

GRANTA EduPack is a unique set of teaching resources and software that support Materials Education across Engineering, Design, Science, Sustainable Development and AM. It provides a comprehensive database of materials and process information including AM, data processing and analysis (Ashby plots), a range of supporting resources: e.g. lectures, projects, and exercises. GRANTA EduPack is divided into three levels so that students access a suitable level of materials information as they progress through their studies i.e. from pre-university up to postgraduate courses. It is used in many different circumstances for teaching materials related to AM: sometimes in well-resourced computer labs, sometimes in self-directed studies using a student's own laptop. It may be fundamentally integrated in the curricula and an essential tool for students in each year; or it can simply be used as a data resource and way of creating great lectures with clear and engaging charts to illustrate concepts.

In the software, there are ideas about how to use the elements database to illustrate trends and relationships between the properties of the periodic table; how simple bubble charts of Young's Modulus v Density can be used to help students understand the different families of materials and what, (e.g., bonding and crystal structure) affects their properties. Students can click through to Science Notes that reinforce the theory and include references to standard texts. Topics such as Phase Diagrams and Crystallography can be covered using interactive tools in the new MS&E Edition of GRANTA EduPack. Heat treatment and other ways to manipulate the properties of materials are also easily illustrated. Students can then go on to select materials for a project based on these properties—developing a perspective on how the fundamental science translates to real engineering applications.

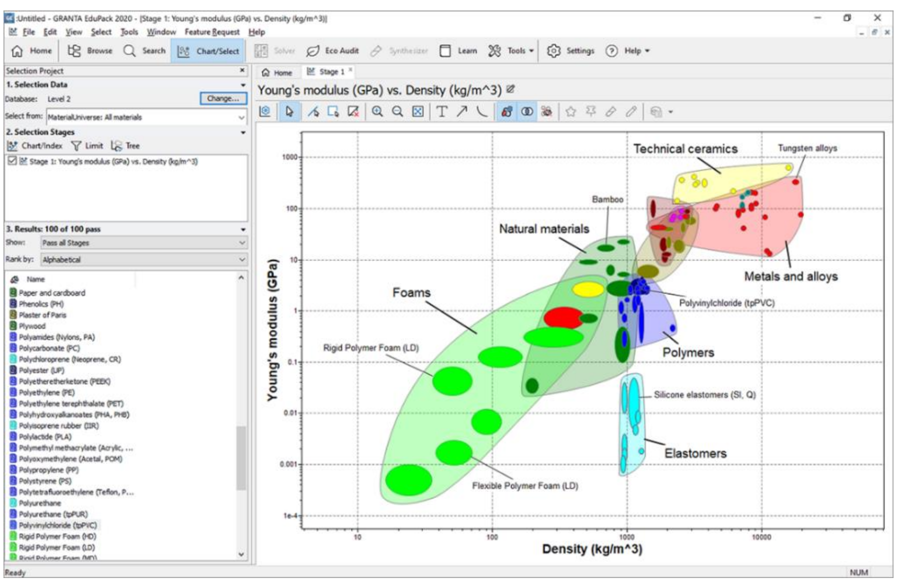


Figure 8: A screenshot of Granta EduPack

Several teaching approaches are applicable when using Granta EduPack software for teaching and learning about materials with a growing number of resources dedicated to AM specific materials and processes:

**A design-led approach**: In this approach, the student begins with a design challenge. The software allows them to identify the materials families that best meet its requirements. They can then explore why different materials perform differently, 'drilling down' into the EduPack information resources to find out more on the underlying science.

**Classroom teaching**: Ready-made PowerPoint lecture units and associated exercise booklets are made available. Customized materials property charts can be created to illustrate the particular point, and copied into PowerPoint, or saved as a project file and opened within the software so that you can annotate the chart in real time during your lecture. The software is also used as the basis for short, hands-on student exercises during classroom sessions, or as 'homework'. The EduPack teaching resources provides such exercises. Students can investigate materials and create reports or posters to prove their learning.

**Project-based learning**: support for student projects, both as a comprehensive information resource and using its materials selection, Eco Audit, and other modelling tools to solve materials-related problems. These projects could be anything from short exercises within an introductory course (examples are provided in the GRANTA EduPack teaching resources) to extensive final-year design projects or even masters-level research projects (using the in-depth data in the EduPack Level 3 database).

**Problem-based learning**: As students use the software to solve design or materials related problems, they can easily 'drill down' into information that explains the engineering and scientific principles behind the properties and materials that they are investigating. This capability is well-suited to problem-based approaches where students are encouraged to broaden their subject knowledge by exploring issues and concepts that arise as they tackle a specific problem.

**Self-teaching**: Enrolment and campus-wide licences of GRANTA EduPack throughout Europe allow every student on the participating course to install the software on their own laptop or PC. This means that GRANTA EduPack can be a powerful aid to distance-learning and other courses that require students to do a substantial portion of their learning remotely or in their own time. Extensive student resources are provided, including 'Teach Yourself' booklets, glossaries, and case studies.

## 7. Pilot Courses Delivered During the SAM Project

As mentioned in the introduction, different pilot courses for professionals were re-worked or introduced during the SAM project. This section is looking at the integration of the above mentioned learning contexts and tools that have been listed in here and help understand which one have been more successfully used than others. As the COVID 19 crisis was hitting right at the beginning of the pilot phase, the majority of the pilot courses was delivered as on-line courses. The members stated that these courses would have, under "normal" circumstances, been delivered as a theoretical and the practical part.

For LMS, theoretical teaching consisted of both a general review of the applied processes and detailed information on the AM process, advantages and disadvantages.

On the practical element of the pilots, attendees were required to create a product using AM techniques. In pilots CU 68 **Design for Material Extrusion** and CU 69 - **Design for PBF Polymers** attendees were asked to create a mobile phone stand using AM processes.

During the training and to increase learner interaction and engagement, live polls were run using Slido (etc) giving participants opportunities to learn more and increase communication with the trainers and improve decision making on the design and finish of the products being created. Polls can be used both in face to face or online learning forums.

## 8. Conclusions

The document provides an overview of the various learning contexts and learning tools available for AM training and education. In terms of learning contexts, a range of contexts from traditional classroom teaching to lab teaching can be found. Due to the CoVid 19 issue, it is expected that online learning will gain significant momentum over the coming years. Learning tools have expanded the technological abilities as mentioned above and the examples now include serious games and TF paradigms.

Overall, it can be highlighted that AM learning is limited at high school and undergraduate level but lots of training contexts and tools are already available for the teaching, learning and practicing of different 3D printing topics at Master/PhD level and for professional development/up-skilling.

A need is seen to translate the specific, advanced postgraduate courses to undergraduate level. In addition, the inclusion of AM topics in secondary education (such as IMR – Irish Manufacturing Research Institute) would be highly beneficial in order to start addressing AM skills development at early stage and to increase the attractiveness of engineering careers amongst young people.

As 3D printing is a fairly new technology, the digitalization process has also already been included for a lot of teaching methods such as augmented reality or serious games. One can choose from a broad field of teaching methods.

However, as it can be apprehended from this paper, the current EU wide educational market offering places AM in a varied and subset position of Engineering courses rather than at the centre of a specific training offering. How teaching is carried strongly depends on the different focus, the schools, expected audience, topic or institution. There is no homogeneous way of teaching or learning that is currently applied by the teaching institutions. In general, the mapping of the different contexts and learning tools showed that a mixture of two different training methods (theoretical and practical) will have the greatest learning effect for the audience. It would be interesting to develop a guideline for what learning context should be adopted with an according training tool in relation with the targeted audience.

In terms of learning contexts, it has been shown that varied teaching methods as well as different topics are covered in AM. One finding is clear, there is a lack of sustainability and green skills development activities across the full process chain from material to part, ecological aspects, raw material consumption etc. is found.

Digitalisation however is an aspect that has been covered quite well. This is probably due to the conjunction of 3D printing and industry 4.0, as both topics work very well together and industry 4.0 can be exemplified using 3D printing.

In terms of training tools, a variety of tools, including digital one are available. Of course, there is always room for improvement. In terms of recommending the right method for the right audience, it depends heavily for which audience which process, or context will be taught. In general, in AM there is a great potential to combine theoretical and practical teaching resources, as small teaching machines are already readily available on the market. For example, online learning (which will significantly grow post COVID-19) is an effective way to reach a wide audience with a lot of different topics. However, this is a theory-based learning tool and in order to fully exploit the potential of AM learning, online learning would need to go along with project based practical learning for a week or two in a teaching factory or laboratory. Exploring a manufacturing ~~or~~ process via augmented reality lets a student access all in a less theoretical way but, the hands-on experience ~~gets~~ is lost and it would be recommended to let the learners experience 3D printing by really touching a machine.

Training challenges during COVID19 and the need for hands-on training forced organisations to adapt, rethink and overcome training methods and practices. To solve this, trainers have started experimenting with virtual learning and integrating new technologies such as augmented and virtual reality as training tools.

Learning Management Systems (LMS), micro-learning and credentials, online interactive activities like Live Polls and IoT along with the augmentation of the Virtual Reality are some of the newly introduced training methods and tools used during the pandemic period and show representatives examples of the new methods and tools. This is also seen in the delivery of the pilot training courses within the SAM project.

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