Innovative Training on Additive Manufacturing: AMTE@CH Learning Experience.

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***Abstract*— Enhancing Additive Manufacturing (AM) education at graduate and professional levels is a strategic lever to improve the manufacturing sector skills. This paper aims at presenting the design of an additive manufacturing training for Vocational Education and Training (VET), developed in the AMTE@CH project. The novelty design of training complements the Instructional Design Model (IDM) with practical activities for AM elevating the awareness of the use of novel pedagogical models for VET. It is fundamental to change the type of teaching/coaching approach, more oriented to active learning and direct participation of students/trainees with project-based learning methods. The innovative AM training method proposed in AMTE@CH project encourages and enables trainers to acquire transversal key competences such as design skills, and technical knowledge on AM.**

Keywords*— *Additive Manufacturing, Innovative Education, Learning, MOOC.

I. INTRODUCTION

Additive Manufacturing (AM) technologies have been identified as one of the keys enabling technologies to improve European industrial competitiveness. AM, also known as 3D printing, is one of the revolutionary intelligent manufacturing technologies that can lead industrial transformation. The key to success of AM is its variety of applications such as aerospace, automotive, medical, art, and construction applications, which requires domain knowledge expertise coupled with appreciation of AM sciences [1-2]. Today, there is a skills mismatch in additive manufacturing and the demand for AM applications is growing. AM is changing the way that manufacturers produce end-use parts and components and innovative education in AM plays an important role in bridging this gap. 3D printing and other technologies are constantly upgraded and innovated, but the teaching content seriously lags behind the actual job skill standards, and students together with job trainees, cannot master the application of cutting-edge technologies so as to meet the needs of additive manufacturing industry [3]. Some barriers such as the lack of knowledge and skills on the use of the technology require the design of complex learning system and the application of effective educational technologies. This change is asked by training institutions, schools and universities that will have to prepare the new workers and enable their constant update even in lifelong learning [4].

AM-TE@CH is a two-year project co-founded by Erasmus + Programme of the European Union, which aims at boosting competences in the field of Additive Manufacturing with a newly developed online training path for Vocational Education and Training (VET) trainers. The aim of AM TE@CH project is to design and to implement an innovative training on additive manufacturing for Continuing-Vocational Education and Training (C-VET). The planned activities are mostly related to the development of a common methodology to: (1) improve the key competences in VET learners; (2) create innovative education practices by means of the model-based 3D printing industrial technology; (3) introduce systematic approaches, and opportunities for the initial and continuous professional development of VET trainers and mentors, in both school and work-based settings. The innovative additive manufacturing (AM) training method proposed in AMTE@CH project encourages and enables trainers to acquire transversal key competences such as design skills, and technical knowledge on AM. It also improves technology readiness and the general assimilation of new AM technologies. Finally, it represents a solution to the shortage of skills.

The following sections review the state of art of educational efforts in the AM field and summarize their main directions presenting their content and learning approach within the AMTE@CH project.

II. ADDITIVE MANUFACTURING AND INNOVATIVE EDUCATION

A. *Additive Manufacturing*

AM is a set of processes where physical objects are made from digital files generated by computer-aided design software [5]. The evolution of the technology to additive manufacturing affects the product development process. With the emergence and proliferation of the technology, there is an increased demand for workforce which can understand principles of additive manufacturing processes and optimally apply it to solve real life world problems. The industry is currently facing challenges with the lack of design for AM principles, process guidelines and standardization of best practices [6]. The importance of additive manufacturing (AM) to the future of product design and manufacturing industries demands innovative educational programs tailored to embrace its fundamental principles and potential [7]. Many public and private initiatives, including research centers and consultancies, have been established to explore opportunities for innovation and adaptation of AM. The rapid growth and disruptive potential of AM technologies demand education programs that address the fundamental principles of AM and likewise enable trainees in AM to realize its capabilities.

As early as 2009, it was identified that AM education is critical to the advancement of the field, and that programs at the university, industry, technical college, management, and general population levels would be needed [8]. Many scholars have noted the need for 'comprehensive student-centred pedagogical models' for AM innovative education. Simpson et al. [9] presented an AM training pyramid that 'connects the entire educational spectrum, from primary and secondary education, to non-engineering students, to AM research and development (R&D) activities'. The pyramid identifies relevant AM/3DP skills and knowledge across the educational pathway to AM careers.

B. *Innovative education*

Innovative education research facilitate the development of the field of Additive manufacturing. Interest in 'Design for Additive Manufacturing' (DfAM) has developed over the last decade. Williams and Seepersad [10] propose problem-based approach and project-based methods for providing students or trainees with a hands-on experience with Additive manufacturing technologies. Chong et al. [11] proposed a blended learning model for inculcating skills required for Industry 4.0 readiness, including additive manufacturing using traditional methods, online learning, and flipped classroom approaches in 3D printing design. The emergent state of AM education necessitates the inclusion of innovative education research efforts to tackle underlying issues as the field emerges, such as those related to curriculum, teaching and learning; development of expertise. The introduction of additive manufacturing education represents an important leverage in the preparation of young engineers and trainees who benefit from it both in terms of personal preparation and in terms of learning and refining different skills [4]. Developments on AM indicate the need to train technical professionals with new skills and in step with the times and with proper education in the use of new technologies [12]. AM education is related to product design and development and production/manufacturing [13]. Among the main advantages of learning and using AM methods and techniques, there are the better understanding and deepening of problems, the improvement of design and visualization skills and the increase in the ability to use computer-aided design applications [4]. It is fundamental to change the type of teaching/coaching approach, more oriented to active learning and direct participation of students/trainees with project-based learning methods. It allows students to learn design and manufacturing through direct interaction with the results of their efforts, improving learning and training and helping to develop their soft skills. Engaging students/trainees in AM learning can promote cross-disciplinary skills based on learning experiences that engage students in real-world problem solving, thus fostering more authentic learning [14]. Students/trainees will face real-world problems, 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. This approache poses considerable challenges for educators and trainers, who are often not trained to implement AM projects and activities that require technological and pedagogical knowledge relevant to the field.

Identify applicable funding agency here. If none, delete this text box.

III. AMTE@CH LEARNING EXPERIENCE

AMTE@CH is an ERASMUS + project that brings together six European organisations for developing an innovative training programme on additive manufacturing, targeting both trainers and the final beneficiaries of the learning experience, i.e. managers, buyers, designer, process engineers operating in the manufacturing sector. The aim of the AMTE@CH project is to offer trainers a basic knowledge of additive manufacturing technologies and materials and their fields of application, while developing the ability to define the most suitable selection strategies for the design of training courses. AMTE@CH project activities aim to bridge the gap between the ever increasing demands of an industrial workforce in Additive Manufacturing and the current state of innovative education. There are two levels of research and work: the first concerns the contents on AM to be selected for training, the second relates to the design skills of trainers working in AM.

A. *Contents for Innovative AM Education*

AMTE@CH project develops an effective and innovative training methodology, high-quality training contents customised for each target group and an e-Learning platform (Moodle). Figure 1 summarizes the Instructional Design Model (IDM) for AM education adopted in the project.

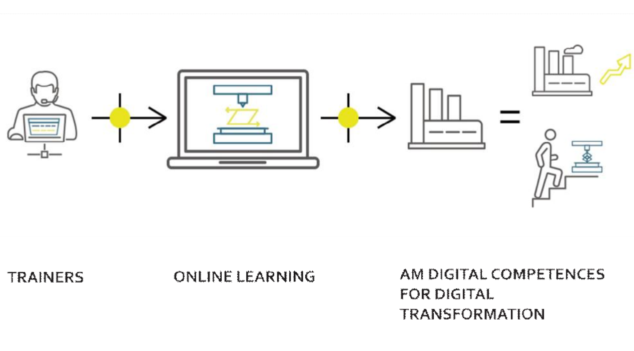

Fig. 1. AMTECH Learning Model

The objective of this IDM is the design of strategies for the reproduction of “authentic contexts” for professionals following a six-dimensional methodology comprising: (I) The selection of authentic tasks that the experts can solve; (II) analysis of the context of solving the authentic task; (III) modelling of experts’ cognitive and behavioral processes; (IV) development of assessment tools for the authentic task; (V) application of instructional strategies to provide authentic contexts by using technologies; and (VI) development of instructional resources and environments [14]. In addition to face-to-face learning experiences such as classroom teaching, online training courses have become a vital aspect of AM education. The beginning of the course is devoted to teaching the fundamentals of additive manufacturing through focus on the cornerstone AM processes. The trainees enrol in the Massive Open Online Course (MOOC) on the AM and engage in the authentic tasks and participate in the laboratories included in the learning pathway. In the first phase the partner of the project team defines the Unit Template (UT) divided into four section:

- Learning outcomes: Identification and definition of several (four or five) learning outcomes for learning content jointly.
- Learning strategy: Development of the learning strategy together which takes in consideration the different places of learning – the university and workplace.
- Learning contents: Selection and production of learning contents related to AM.
- Support documentation and feedback: Discussion of the documentation (learning diary or portfolio) supporting the learning processes and outcomes. Writing of feedback to give support to the learning process (formative feedback).

There are six different modules envisaged in this MOOC generic structure of the AMTE@CH training course: Module 1: Selection of parts, Module 2: Post processing, Module 3: Product evolution, quality assurance, Module 4: Design guidelines and design for AM, Module 5: AM Technologies, Module 6: AM industrialisation. Depending on the type of online learning different learning approaches are applied.

B. Design strategies and skills in AM education

The literature on AM education is rich in examples showing and discussing specific arrangements of AM-centred courses and modules, e.g. the value brought on by hands-on activities and projects. Some studies [15] stressed the effectiveness of hands-on activities, the relevance of managing design guidelines for AM in the learning process and the positive evaluation of laboratory experiences and the investigation of educational practices related to AM. Diegel et al. [16] described the use of problem-based learning for teaching DfAM. The authors stressed the importance of real-world problems and first-person involvement in 3D printing to understand the intricacies and impacts of AM factors. This problem-centre method enables students to become proactive to investigate problems, which competencies are necessary to solve them. Different learning contexts are currently provided for AM training. The type of learning context depends on the specific learning outcomes. A summary of learning context adopted in AMTE@CH are listed, as below:

- Project-based learning (PjBL): support for student/trainees projects, both as a comprehensive information resource and using its materials selection, Open Educational Resources (OERs), 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 OERs) to extensive final design projects or even research projects.
- Problem-based learning (PBL): As students/trainees 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 learners are encouraged to broaden their subject knowledge by exploring issues and concepts that arise as they tackle a specific problem.
- Self-teaching: Enrolment in the MOOC allows every student/trainees to access resources (OERs) and networks necessary to improve AM skills. MOOC can be a powerful aid to distance-learning that require learners to do a substantial portion of their learning remotely or in their own time. Extensive learners resources are provided, including ‘Learning Diary’, glossaries, and case studies.

C. Hands-on activities and labs experiments

An important aspect of training in the field of AM are hands-on activities and lab experiments. 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. Distance laboratories (remote or virtual) are used in different educational areas. Related to AM in the context of distance education, virtual lab emerges as an excellent tool for education purposes for learners. Thus, by usage of these virtual labs students/trainees can perform practical as given by the teacher/expert as well as they can give feedback. Web-based educational resources have gained enormous popularity recently and are increasingly becoming a part of modern educational systems. Virtual Labs are good learning opportunities where learners can gain the experience of practical experimentation without any direct physical involvement on real bench work. They use computerized simulations, models, videos, animations and other instructional technologies to create interactive content [17]. Virtual Labs allow performance of experiments without real world instrumentation needs. Most of these virtual experiments are simulation based and developed using proprietary or Open Source simulation. A four-dimensional goal model is developed for laboratory education. This model [18] is built starting with the educational goals:

- Conceptual Understanding Laboratory: support understanding and solution of problems related to topics covered in the learning pathway. Illustrate topics, concepts and principles.
- Design Skills Laboratory: supports students/trainees to solve open-ended problems through the design and construction of new artifacts or processes. Ability to design and investigate.
- Social skills Laboratory: supports to increase students/trainees productivity by working in teams. Enhance social skills and other team behaviors, e.g. communication, problem solving, leadership.
- Professional skills Laboratory: supports acquisition of technical skills that students/trainees are expected to have when practicing a profession.

In this AMTE@CH training course different types of Professional Skills Laboratories are being designed to support the acquisition of technical skills useful for working in the additive industry sector. After the students/trainees become familiar with the operation and limitations of basic AM technologies via the labs and hands-on activities, the outcomes of the learning pathway will be evaluated in order to improve it.

D. Authentic assessment

Students will be assessed during the different phases of the MOOC. In each of the six MOOC modules, three types of assessments will be implemented: content quizzes, self-assessment and peer assessment. In the MOOC authentic assessment by the production of the final project will be implemented. Authentic assessment can play a role in improving the learning experience of higher education students and working trainees through enhancing their engagement in learning and improving their satisfaction as well as positively influencing their efforts to achieve educational goals [19]. Advantage of the authentic assessment approach is to provide students/trainees with the key abilities and skills that will be required of them in their professional lives. Involvement in “real context” and feedback is also crucial for performing in a professional setting since feedback can guide individuals and determine the shortcomings of their performances so they can improve them. For this reason, the safety aspect is also important and thus a reason for teacher-supervision.

IV. Developing a Framework for an AM Curriculum Leveraging Innovative Education

AMTE@CH framework consists of several recommendations for future implementations of an innovative AM curriculum. First, the importance of clarifying projects and learning pathway goals to be designed. This study adopted the Instructional Design Model (IDM). Starting with this model, the team project defines the learning outcomes, strategies and contents for designing an effective pathway on AM. Second, it is fundamental to define the learning approach such as Project-based learning (PjBL), Problem-based learning (PBL) and Self-teaching to design hands-on activities and labs. Use of digitally archived content, both related to AM, and on supporting topics (e.g., machine design, controls, materials processing) can help adapt trainees/students of diverse skills or backgrounds to the breadth and depth of the AM curriculum. Third, the project activities recognize the importance of the full suite of AM technologies including in the learning pathway, and of designing virtual or remote labs in which students/trainees can test and try out their acquired skills.

V. Conclusion

In this paper, the design stage of the AMTE@CH Erasmus+ project has been proposed, specifically devoted to model innovative training on additive manufacturing for VET and a MOOC. The project has just concluded its first year of activity, during which the methodology and several contents on AM have been developed. In the context of AM education, the project has adopted an innovative teaching approach to develop design-based skills and opportunities for learning AM in highly motivating technological environments. The plan for trainees professional development and the subsequent experimentation of the AM design-based teaching approach is also presented. The project highlights the relevance of an innovative education by promoting digital educational environment (MOOC) in which the AM contents can be easily embedded into a multidisciplinary learning path including high-quality OERs. In the next few months, the results gathered by collecting trainees’ feedback from their designing course and the subsequent in-working experimentation will support an improvement of the methodology for defining the innovative learning path on AM. Finally, the instructional designers or trainers working in AM are not working on a specific skill but on a set of interactions. The educational environment, which is the (at least partially) tangible output of the design process, is a set of possible interactions, not a system with definite predictable outcomes. The organised approach of the IDM allows the project team to adapt and update the learning content, indeed all lessons and activities are divided into different learning stages, so that the final product has the desired effect on the learners. This flexibility and the open source framework are the added value of the methodology used.

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