A Teaching Factory Knowledge Exchange Network

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Abstract

Skills and competences required by the labor market evolve at a high rate. In addition, manufacturing enterprises face a number of technical and non-technical challenges in their daily business, and most of them are relatively slow as it regards innovation adoption. Academia needs to be able to closely follow industrial needs, to generate the right kind of professionals. In addition, academia owns a lot of high-value specialized industrial equipment, which is not shared and subsequently often underutilized. Over and above, COVID-19 has significantly impacted the educational institutes' operation. All aforementioned facts point to one specific need; an effective remote collaboration paradigm aiming at knowledge exchange. The Teaching Factory paradigm provides a real-life environment for students to develop their skills and competences, through directly involving them with real-life industrial challenges. Through the use of modern digital technologies and tools, and in combination with the relevant educational approach, a two-way online knowledge communication between academia and industry is formed, aiming to mutually benefit both stakeholders. This work focuses on presenting a framework for successfully extending the established Teaching Factory paradigm on a network level, taking advantage of the unique characteristics of all aforementioned actors and connecting them together to the ecosystem benefit, forming a Teaching Factory Knowledge Exchange Network. The educational approach and required ICT infrastructure for the facilitation of knowledge exchange are presented. The proposed framework and tools applicability are validated in two heterogeneous pilot applications, using different modalities of the proposed framework, involving a collaborative academic teaching scheme via virtually interconnected classrooms and labs, as well as a collaboratively solving an industrial challenge linked with digital work instructions in manual assembly.

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Keywords: Teaching Factory Network; Collaborative teaching; Interconnected classrooms; COVID-19

1. Introduction

Manufacturing education, as well as the manufacturing sector at large, is entering a new era, where novel life-long learning schemes are required to keep up with the rapid advances in production-related technologies and tools [1, 2]. Skills and competences required by the labor market evolve at a high rate. In addition, manufacturing enterprises face a number of technical and non-technical challenges in their daily business, and most of them are

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relatively slow as it regards innovation adoption. Academia needs to be able to closely follow industrial needs, to generate the right kind of professionals. In addition, the ongoing COVID-19 crisis demonstrated an increasing need for flexibility to comply with rapid shifts in priorities. Current education practices fail in fulfilling the aforementioned requirements. Manufacturing is a subject that cannot be treated effectively only inside a classroom, whilst industry can only evolve through the adoption of new research results. New approaches are required for manufacturing education in order to i) modernize the teaching process and bring it closer to the industrial practice, ii) leverage industrial practice through new knowledge, iii) support the transition from the manual to the future knowledge workers and shorten the gap between resource-based manufacturing (labor and capital) and knowledge-based manufacturing (information and knowledge) and iv) establish and maintain a steady industrial growth [3].

To effectively address the emerging challenges for manufacturing education and skills delivery, the educational paradigm in manufacturing needs to be revised. Many educational institutions have tried to bring their educational practice closer to the industry with the concept of a Learning Factory (LF) [4-[8]. A drawback of this approach is that LFs typically imply ownership of high-value state of art equipment, which is installed on the academic premises and as such is often underutilized. In addition, the dedicated equipment may at some point become obsolete. Consequently, dedicated LFs have the intrinsic limitation of narrowing down their scope, based on the existing equipment. Over and above, the COVID-19 pandemic has introduced additional challenges, leading to more than 191 country-wide closures [9], significantly affecting operation of LFs among others. Attempting to overcome these challenges, the Teaching Factory (TF) has emerged as a promising paradigm for manufacturing education, and has shown its' potential over numerous applications over the years [10-14]. The TF operates in a non-geographically anchored learning "space" interconnecting remotely located engineering and student teams that work together on real-life projects. TF is facilitated by advanced ICTs and high-grade industrial didactic equipment and operates as a bidirectional knowledge communication channel "bringing" the real factory to the classroom and the academic lab to the factory [15]. Context and content modular configurations allow learning and training on multiple study contents, engaging different factory facilities, engineering activities, delivery mechanisms, and academic practices.

2. The Teaching Factory Knowledge Exchange Network

This work focuses on presenting a framework as well as application examples for successfully extending the established TF paradigm on a network level [16], forming a Teaching Factory Knowledge Exchange Network (TFKN). The network links industrial and academic / research actors (nodes) and facilitates the launch of collaborative manufacturing training projects with mutual interest. Participating organizations can effectively exchange information, including teaching material, virtual access to state-of-art infrastructure, real industrial challenges and novel solutions. These organizations are classified into two boards. The academic board (comprising universities and RTOs) focuses on providing novel concepts, approaches, and remotely-accessed test-beds to address both industrial needs and innovative educational schemes. The industrial board has the chance to express their needs in terms of training and upskilling personnel as well as provide a number of industrial challenges to be elaborated by the developed TFKN. Each challenge along with the knowledge/solution generated can be shared with the complete network (on a confidentiality basis), creating value across all participating entities (Fig. 1). As such, a TFKN can operate in multiple knowledge transfer modes: i) "Industry-to-academia" aiming at transferring the real manufacturing environment to the classroom through the adoption of an industrial project involving one factory in a simultaneous interaction with one or several classrooms. This interaction can involve discussions, presentations, live videos from the production, and other knowledge delivery mechanisms. ii) "Academia-to-industry" aiming at transferring knowledge from academia to industry. Test-beds and demonstrators for new technological concepts are installed into academic facilities (LFs) in order to be validated by students and researchers or used for professionals training and upskilling. This interaction can involve live audio/video interactions between the industry offices and academic labs, as well as remote interaction with the physical test-beds through advanced ICT tools [17]. iii) "Academia-to-academia", aiming at linking academic nodes with specialized know-how and equipment in order to collaboratively teach students an engineering subject, through virtually interconnected classrooms and labs.

To enable effective operation of the network, an ICT platform integrating all functions necessary to perform a TF project is required. A web-accessible platform is prioritized, due to the requirement for it to be accessible through multiple devices (PCs, tablets, smartphones). The core functionality is the ability to facilitate video conferencing, enabling synchronous communication between TF project actors. To facilitate asynchronous communication between these actors, a collaborative working space is needed, including a repository to facilitate file storage and exchange, collaborative editing, as well as storage of recorded video sessions. In addition, a tool to facilitate open discussion/chat between actors, as well as a number of basic organizational/planning tools to aid the organization of TF sessions are required. In this particular instance, utilization of a commercially available platform (MS Teams) was preferred, as it could readily support all aforementioned requirements. To allow efficient management and organization of the activities, three main types of users have been envisioned; Coordinators, Tutors, and Trainees. Coordinator(s) are the main contact point(s) from each partner, responsible for the overall planning of the activity, and have open access to all ICT tools and working spaces. Tutor(s) are experts from industry/academia, guiding the execution of the technical part of the activity. For teaching/training activities, the role of the tutor is the one of the educator, preparing and presenting the education material to trainees. In addition, for Industrial projects, the role includes recommending/advising approaches, supervising the work that is being developed by the Trainees, and, finally, evaluating their performance in two perspectives (technical and soft-skills). Trainee(s) are participants coming either from academia or industry, being educated or upskilled.

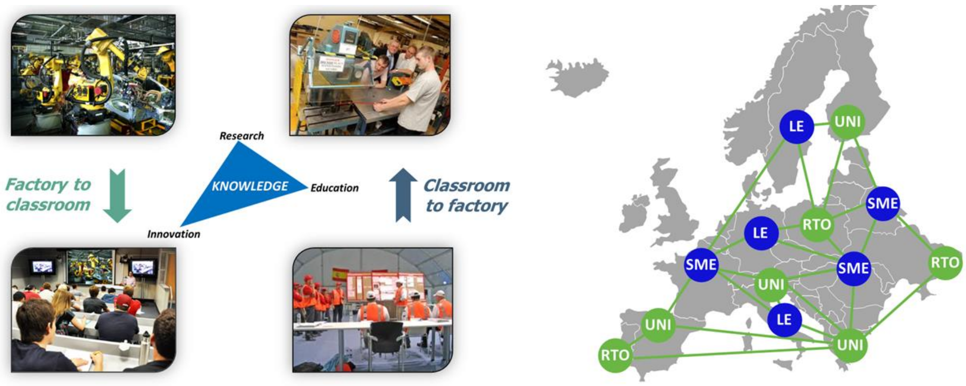

Fig. 1. TF KnowNet approach (SME – Small Medium Enterprise, LE – Large Enterprise, UNI – University, RTO – Research Technology Organization)

3. Implementation

To validate the proposed framework and tool applicability, two heterogeneous pilot applications have been implemented. These pilot activities acted as the proof of concept of TFKN and involved 2 modalities; an industry-to-academia pilot and an academia-to-academia pilot. The industry-to-academia pilot involved addressing an industrial challenge imposed by one of the industrial partners, and teams from all participating universities responded to it. Knowledge transfer occurred both ways; from industry to academia regarding state of art practices and challenge establishment, and from academia to industry regarding state of art research and potential solutions. The academia-to-academia pilot involved collaborative and interactive teaching of manufacturing processes and was executed between the academic partners with the involvement of industry demonstrating application examples.

3.1. Industry-to-academia pilot

The aim of the industry-to-academia was for the students to collaboratively work on solving an industrial challenge.

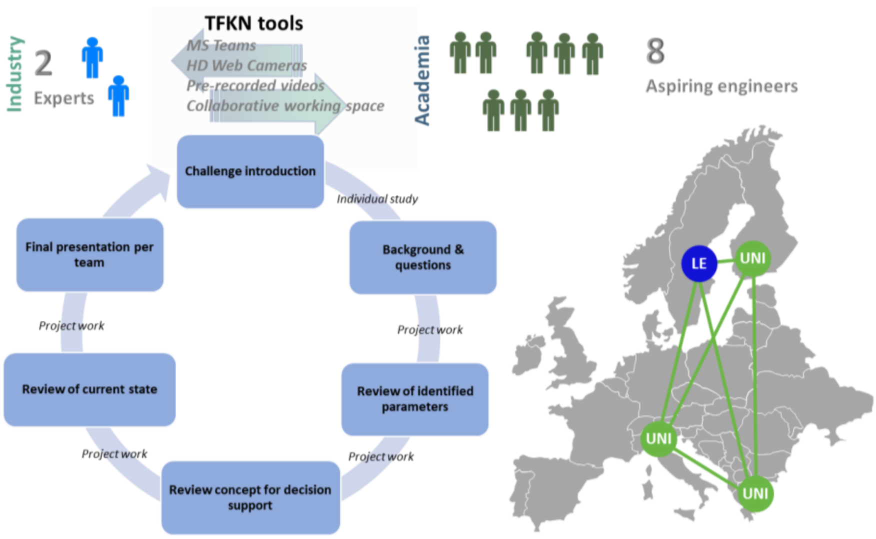

Fig. 2. Industry-to-academia pilot overview (LE – Large Enterprise, UNI – University)

For this particular implementation, the challenge presented by Volvo Trucks, with the participation of trainees and tutors from LMS, Aalto University, and Politecnico di Milano. The challenge was focused on introducing digital and dynamic assembly work instructions in a manual assembly context of heavy-duty trucks. The customization level of a truck corresponds to the specific requirements of each customer. Due to the number of options each operator needs to consider due to the high level of product variety, a number of measures to deal with complexity and perceived complexity are in place. Due to the increased handling of high product variety, the operators require better decision support during their assembly tasks. This decision support needs to consider multiple parameters that affect the ability of the operator to perform an assembly task as required. The challenge was divided into two assignments, (i) identify different parameters that could both positively and negatively affect product quality, adherence to decided assembly steps according to the decision support and (ii) address the most important (impact) identified parameters by proposing how (logic) such a parameter could be used in decision support functionality. The pilot spanned a duration of 10 weeks, with 2-hour sessions between Volvo and the students taking place every 2 weeks on a fixed timeslot, to monitor progress and guide the students. In total, 8 students forming 3 teams participated in the pilot, with each team developing a different approach and presenting a different potential solution to the challenge, as summarized in Fig. 2. In order to evaluate the pilot outcomes, the Learning-Transfer Evaluation Model (LTEM) [18] was used. According to this model, evaluation of learning outcomes should be done in 8 levels; Attendance, Activity, Learner Perceptions, Knowledge, Decision Making, Task, Transfer and Effects of Transfer. It is worth mentioning that LTEM should be used as a roadmap, and different levels/metrics used in accordance on what is evaluated. In this particular pilot, the first 7 levels of LTEM were evaluated, based on feedback from both the learners and the tutors. The results are satisfactory, with 100% attendance and activity of participants, as well as very high knowledge retention. Moreover, Decision Making, Action Taking, and Transfer are evaluated as very positive, as all students completely understood the challenge, were actively communicating new concepts and ideas, and were able to effectively and timely transfer their knowledge and new concepts to the tutors via the final presentations. In addition, and combination with the LTEM methodology, an evaluation questionnaire was created in order to capture the satisfaction and feedback of the participants. The participants were asked to evaluate the content, assigning a score from 1-5, and the findings of the evaluation are summarized in Fig. 3.

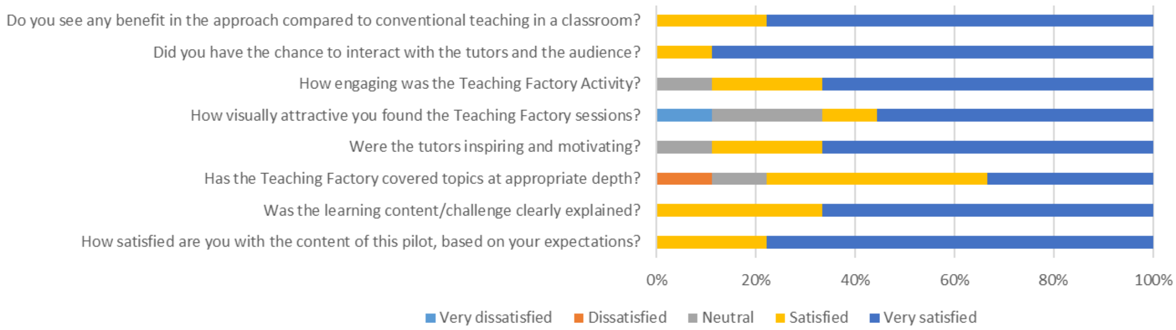

Fig. 3. Industry-to-academia evaluation questionnaire results

The main benefits pointed out by the participants were the chance to observe closely a real manufacturing factory and real-working environment, be in touch with problems and difficulties, capabilities and efficiencies and identify challenges about the assembly operations. The active interaction with the industry was also emphasized, stating that it gave additional motivation to trainees to go even deeper into the project and all its features. Furthermore, the participants pointed out the importance of becoming creative in making innovation and developing ideas, and being able to observe different outcomes of the project. At the same time, the pilot had a positive impact on the industrial side, generating three different potential ideas on how to tackle the challenge at hand. Feedback from the industry was also positive, pointing out the heterogeneity between the approaches and proposed solutions elaborated by the three different student groups.

3.2. Academia-to-academia pilot

The academia-to-academia pilot was implemented as a collaboration between LMS, Aalto University, Mondragon University, and Prima Additive. Tutors and lab facilities from all 4 partners were utilised (based on the expertise and specialised existing infrastructure), while trainees came from all 3 participating Universities. The aim of the pilot was to introduce students to different types/families of manufacturing processes, aiding them to understand the benefits, limitations, and application areas of each process, as well as evaluate process selection criteria. In addition, it provided practical insight on implementing said processes to manufacture real parts and the associated challenges of each. The pilot had an overall duration of 10 weeks, with a 2-hour live session taking place every week on a fixed timeslot. Five process families (joining, material removal, additive manufacturing, forming and deforming) were examined. Each process was first presented theoretically via a lecture and was followed by a practical lab demonstration the following week (Fig.4), where the students observed in real time how the machine/process operates and how different process parameters affect the outcome, both in terms of part quality but also in terms of other KPIs such as time and energy required. Student performance was evaluated based on attendance and on questionnaires/quizzes, created and evaluated by the topic responsible and implemented as multiple choice quizzes via the MS Teams working space. Students were given one week to reply to the questionnaires, while they also had access to the enhanced teaching material used during the live sessions, via the MS Teams working space. In total, 53 students participated in the pilot.

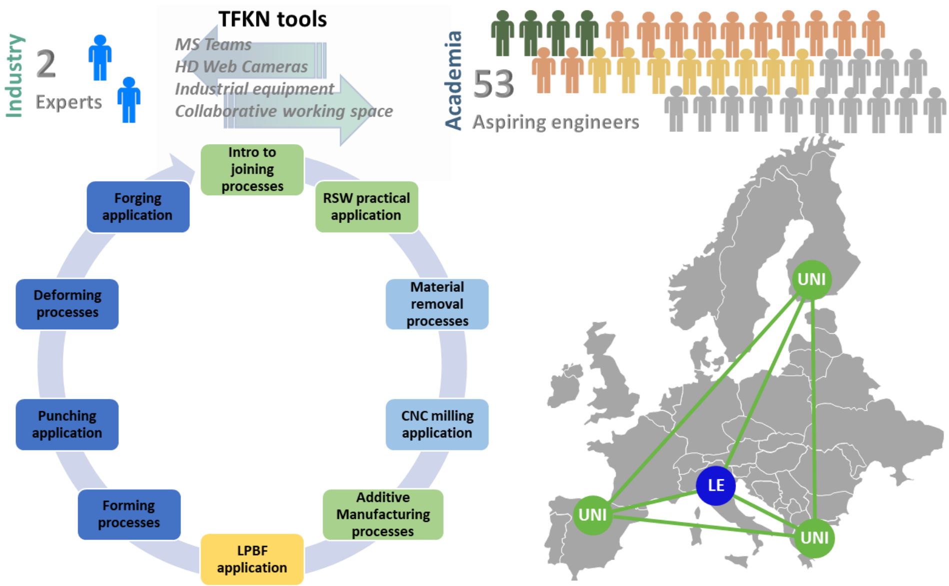

Fig. 4. Academia-to-academia overview (LE – Large Enterprise, UNI – University, RSW – Resistance Spot Welding, LPBF – Laser Powder Bed Fusion)

Similar to the industry-to-academia pilot, LTEM (and particularly Levels 1-4 in this case) was used to evaluate the pilot outcomes. The results were satisfactory, with 97.2% attendance and activity of participants, as well as very high knowledge retention, measured by an average 82% score in the quizzes. Moreover, an evaluation questionnaire was also used to capture the direct feedback of the participants, and the findings graphically summarised in Fig. 5.

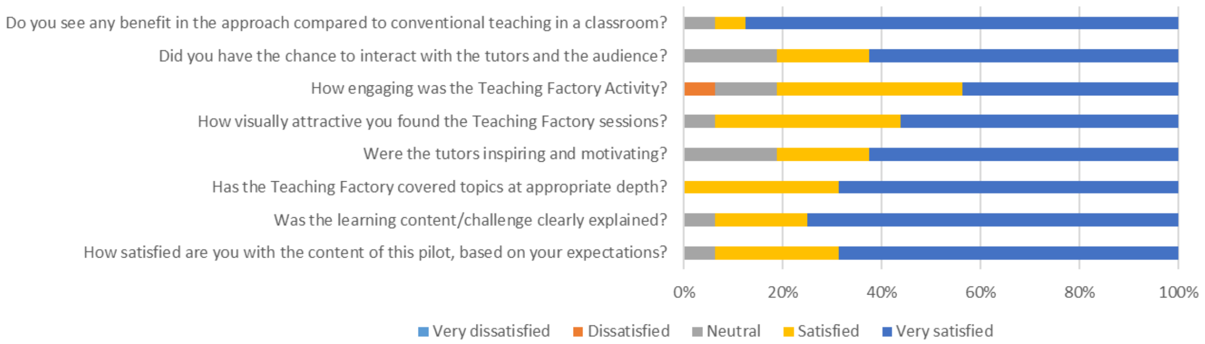

Fig. 5. Academia-to-academia evaluation questionnaire results

The main benefits pointed out by the participants were linked to the fact that the pilot was a more engaging way of teaching than the conventional classroom approach, and the opportunity to observe new (to them) processes and industrial practices that otherwise would not be accessible due to lack of such equipment in their respective universities, while also interacting in a live manner with them. The international environment and engagement of different experts were also perceived as high-value. In addition, the benefits of remote learning and the potential for asynchronous learning via the recorded sessions was also highlighted. The practical aspects and lab exercises was pointed out as the favorite part of the pilot by most participants.

4. Conclusions

The Teaching Factory Knowledge Exchange Network paradigm can be deployed as a novel approach towards digitalized education, enabling remote teaching and training through virtually interconnected classrooms and factories. Virtual classrooms and working spaces can enable collaborative teaching while promoting teamwork without the requirement of physical presence. Live audio and video interactions can be performed between industry offices and academic classrooms or labs without the need for traveling and physical interaction. The development of online working spaces can further enable asynchronous collaboration and overcome any timeframe and availability limitations between the academic and industrial partners. Besides transitioning to a teaching and education scheme more suitable for the post-COVID world, benefits arising from such a synergistic approach include effective exploitation of the expertise of individual partners' knowledge, sharing of high-value infrastructure through virtually interconnected labs, closer matching industrial skill needs, and gain attractiveness, as well as promotion of multi-nation and multi-cultural communication. Future work may involve further extending the knowledge exchange network, as well as introducing connected equipment, such as machines with embedded sensors, actuators, and cameras connected to the network using IoT devices. In addition, Virtual or Augmented Reality can be utilized to optimize the user immersion into the environment, enabling access to all. They could also contribute towards further enhancing the overall experience of distance learning and significantly reduce the gap between remote and physical access, augmenting the TFKN approach.

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