The Teaching Factory: A Manufacturing Education Paradigm

G. Chryssolouris*, D. Mavrikios, L. Rentzos

*Laboratory for Manufacturing Systems and Automation, Dept. of Mechanical Engineering and Aeronautics, University of Patras, Patras, 26500 Greece

Abstract

The Teaching Factory paradigm aims to align manufacturing teaching and training to the needs of modern industrial practice. Future engineers and knowledge workers need to be educated with new curricula in order to cope with the increasing industrial requirements of the factories of the future. The Teaching Factory paradigm comprises the relevant educational approach and the necessary ICT configuration for the facilitation of interaction between industry and academia. The Teaching Factory aims at a two-way knowledge communication between academia and industry. Both knowledge channels of the paradigm are presented, in the context of this work, within real-life industrial applications. The Teaching Factory paradigm provides a real-life environment for students and research engineers to develop their skills and comprehend the challenges involved in everyday industrial practice.

© 2016 The Authors. Published by Elsevier B.V.

Peer-review under responsibility of the scientific committee of the 49th CIRP Conference on Manufacturing Systems

Keywords: Learning; Design; Teaching Factory;

1. Introduction

Manufacturing enters a new era, where novel life-long learning schemes need to keep up with the rapid advances in production related technologies, tools and techniques [1]. Considering the importance of manufacturing as a wealth generating activity for any nation, the promotion of excellence will become a strategic target in the years to come. Manufacturing education will comprise a major driver towards that direction [2]. However, teaching and training have not kept pace with the advances in technology. The current practice is lacking a continuous delivery of engineering competencies and strong multi-disciplinary background [3]. The transformation of research results into new products and processes is inadequate. Modern concepts of training, industrial learning and knowledge transfer schemes can contribute to improving the innovation performance of European manufacturing [4]. 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) modernise 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.

To effectively address the emerging challenges for manufacturing education and skills delivery ([5], [6], [7]) the educational paradigm in manufacturing needs to be revised. Many educational institutions have tried to bring their educational practice closer to industry ([4], [8], [9], [10]) also with the concept of a Learning Factory. A drawback of this approach may be that the dedicated equipment, which is installed on the academic settings, may at some point become obsolete. Consequently, dedicated learning factories have the intrinsic limitation of narrowing down their scope, based on the existing equipment.

The Teaching Factory approach presented in this study aims at a much broader use of novel learning methods for the introduction of young engineers to a wide spectrum of manufacturing problems. At conceptual level, an extended Teaching Factory paradigm, based on the knowledge triangle
notion, has been suggested ([11], [12], [13]). The aim is to effectively integrate education, research and innovation activities into a single initiative, involving industry and academia. Towards that end, the proposed Teaching Factory paradigm focuses on integrating industry and academia, through novel adaptations to the teaching / training curricula, achieved by the deployment of ICT-based delivery mechanisms.

2. Teaching Factory Concept

The Teaching Factory concept is based on the knowledge triangle notion [14] [11]. The concept of the Teaching Factory has its origins in the medical sciences discipline and specifically, in the paradigm of the teaching hospitals, namely the medical schools operating in parallel with hospitals. It aims to incorporate the learning and working environment from which realistic and relevant learning experiences arise.

The Teaching Factory follows a two-way knowledge transfer channel, where manufacturing topics are the basis for new synergy models between academia and industry (Fig. 1). The technological topics are independent of the Teaching Factory’s operation and can be updated in order to provide the necessary knowledge foundation for the needs of manufacturing at any given time. The knowledge transfer channels are used for the exchange of novel ideas and solutions, balancing the time and cost required for learning and testing such solutions and deepening the knowledge of both industry and academia through production innovation or real-life problems.

This two-way knowledge transfer channel includes two different Teaching Factory operational schemes, namely, those of the “factory-to-classroom” and the “academia-to-industry”. The “factory-to-classroom” concept of the Teaching Factory aims at transferring the real production/manufacturing environment to the classroom. The real life production site has to be used for teaching purposes in order to enhance the teaching activity with that of knowledge, existing in the processes of every day industrial practice. Delivery mechanisms that will enable classroom students to apprehend the production environment, in full context, need to be defined and developed. This concept mainly focuses on the “virtual enterprise” type of operations with training services delivered on a virtual basis. The configuration layout of the factory-to-classroom concept should follow a modular approach to allow flexibility on its application and operation. Multiple layout options are possible when different modules of the Teaching Factory are being combined. Moreover, such sessions could accommodate multiple knowledge receivers. The configurations of the Teaching Factory sessions could follow either a “one-to-one” approach that is one factory to one classroom, or, a “one-to-many” approach, which involves one factory, in a simultaneous interaction with many other classrooms.

The modularity of the Teaching Factory concept, whose modules describe the options of the factory-to-classroom operation, is presented in four categories (see Fig. 2). The different modules listed in the four categories can be combined with various configuration layouts. The modules mentioned should be recognized as exemplary. The first category is the “Factory”, which represents the different modules corresponding to the production areas and processes, involved in the Teaching Factory. The second category defines the curriculum / study content delivered in the Teaching Factory. The third category is populated by the delivery mechanism modules. The delivery mechanisms are responsible for the communication of knowledge and interaction capabilities between the factory and the classroom. The expression “Delivery Mechanism” does not imply a linear delivery of the knowledge. Knowledge, and particularly competency is constructed by the participants with the help of the IT-infrastructure and the teaching staff. The fourth category is the delivery ICT technology such as dedicated to video conferencing or web services. Finally, the fifth category includes the courses, corresponding to the configurations that will accommodate the Teaching Factory session, within the educational activities. The Teaching Factory will operate in different options allowing flexibility in order to avoid possible limitations. These limitations may result from the technological infrastructure available and can be time and cost
related. The IT-Infrastructure Layout specifies the delivery mechanisms and defines the interfaces of the IT-Infrastructure with the classroom, the conference room, the factory and further connectable devices. Additionally, it describes the way that the knowledge transfer from the factory to the students will be managed.

The “academia-to-industry” operational scheme aims to transfer the knowledge from academia to industry. Industrial-grade or didactic equipment installed into the academic facilities can be used as test-beds and demonstrators for new technological concepts to be validated by students and researchers. The technology and knowledge can be then transmitted back to industry for introducing an engineering or management team to the new concept or solution. The “academia-to-industry” scheme can also be used for training and re-training operators on new manufacturing technologies and concepts. There are many manufacturing concepts that might be too costly and time consuming to be industrially tested on their actual production. The Teaching Factory can be a useful facility for the validation of such concepts, while closing the gap between production innovation and education.

3. Teaching Factory Implementation

The implementation of the “factory-to-classroom” operating scheme is carried out through the adoption of an industrial project. The purpose of the project is to bring together in overlapping time and in the same context, the industrial and academic practice (see Fig. 3).

The industrial problem may include a specific set of tasks in the product / production lifecycle. For example, an industrial project can focus on the line balancing of a new production line which is normally carried out during the detailed engineering phase (Fig. 3). It is broken-down into sub-tasks distributed to student teams. The students work on this problem’s solution using modern ICT technologies for their communications with the engineers and the tools necessary for the development and validation of their ideas and solutions. The project is supported by an educational approach that integrates the details and logistics into the academic practice, together with an ICT approach that facilitates the interaction between factory and classroom.

The industrial project is addressed through a weekly cycle of sessions, comprising supporting classes, project work and live interactions with the factory (Fig. 4). Each working session is characterized by a live interaction with the factory. This interaction includes discussions, sharing of presentations, live videos from the production and other knowledge delivery mechanisms, depending on the content of the problem. In between the live sessions, the students have to carry out project work, which may involve experimentation or data analysis to derive conclusions and new solutions. The supporting classes are moderated by an academic supervisor, who is also responsible for triggering the discussions and providing guidelines in search of solution paths.

4. Applications

4.1. Construction Equipment

This real-life pilot was conducted among university students and engineers working at a construction equipment factory in Europe. The industrial problem addressed in this “factory-to-classroom” pilot was the line balancing of a new production area for the construction equipment factory. The pilot lasted seven weeks. Each week, the Teaching Factory session would take place in the form of seminars between the students in the classroom and the engineers in the factory, covering a variety of subjects ranging from introduction to the problem, discussion and initial theoretical approach, to evaluation of draft model, results and presentation of solutions. The classroom dedicated to each Teaching Factory session of the students, was specifically built for “tele-learning” operations and provided the necessary means of hosting this pilot, while maintaining a good interaction quality (see Fig. 5).
The students performed the validation of new concepts for the factory, using discrete event simulation. Production engineers and simulation experts were interacting with the students during the sessions. Through experimentation, the students were able to define the workload strategy for each station of the line, to investigate the effects of the workload on the system’s output and to find out the system’s sensitivity to any deviations in the processing times. Furthermore, within the context of the industrial problem, the students had to plan the material flow in the line in terms of human resources and equipment.

They provided an understanding of the optimal positions of the different component types, depending on the variability of the product, while defining the location of the handling equipment and human resources in order for the material feeding process to be carried out. The students managed to identify bottlenecks creating disturbances in the assembly line of the production area. The suggestions of the team led to an updated production to prevent bottlenecks.

4.2. Industrial Automation

The second pilot operated under the “academia-to-industry” channel. The focus here was the knowledge transfer from an academic to an industrial environment. A company producing automation and control equipment was the industrial partner for this pilot. The scenario comprised didactic manufacturing equipment, located in academic premises in order to demonstrate new solutions at a low cost. The purpose was to showcase research results to industry in order to get feedback from people that could potentially adopt such concepts to real industrial practice and improve the quality of work. At the same time, industry got access to research work with minimal effort.

The content of the pilot was to demonstrate the academic partner’s research work on mobile robots and flexible robotic cells, while investigating the way that they could apply this knowledge to industrial problems. Two demonstrators were selected, a car chassis robotic welding (cooperating robots – see Fig. 6) and a razor handling cell (industrial and mobile robots – see Fig. 6).

4.3. Machine Design

The industrial problem given for the presented Teaching Factory project, involved the case of designing a Multi-Technology Platform (MTP) that combines a milling working center with a robotic arm equipped with a laser head (Fig. 8). The simultaneous application of thermal load and vibration affect the performance of the machine in terms of dimensional accuracy and stability. The students had to design the swivel table in collaboration with the machine shop where the MTP would be installed. The industrial requirements were given in the form of specifications regarding the static compliance, thermal load and dynamic compliance of the final product.

The pilot was organized in five collaborative cycles, through which the students would interact with the machine shop in order to solve the problem following the design cycle of the particular industrial practice (Fig. 9). The real-life industrial problem was presented to the students on the academia side. The second cycle focused on the definition of the design specifications based on the
prerequisites defined in the first cycle. The feedback that the students received from the machine shop during the first two cycles was used for drafting an initial design within the third cycle of the pilot. The fourth cycle was focused on the detailed dynamic and thermal analysis of the selected design. Finally, during the fifth cycle the students presented their final solution as a result of this collaborative design process (Fig. 10).

5. Future Work

The modular nature of the Teaching Factory may suit the needs and limitations of both the academia and industry. Not all manufacturing problems can have their solution worked out via methods selected for the pilot cases of this study. This is the reason why the Teaching Factory asks for a high-degree of modularity when adopted for academic and industrial practice. New ICT technologies may help the concept to be implemented. There is room for the ICT technologies of the Teaching Factory to be improved in terms of didactic content.

Future work may involve multiple, remotely located “factories” and “classrooms”. The Teaching Factory can also have a significant impact on vocational training. New technologies and manufacturing concepts can be transmitted to operators working in an industrial environment. Furthermore the use of the Teaching Factory concept may encourage entrepreneurship in universities and innovation within companies, through shared projects between academia and industry.

Acknowledgements

The work presented in this paper is partially supported by the Knowledge Alliance project KNOW-FACT, namely Volvo Technology (construction equipment pilot), Festo AG (industrial automation pilot), Fundacion Tecnalia, Politecnico di Milano, Technische Universität Darmstadt and Consulting and Software Products S.A., for their cooperation. In addition, the authors would like to express their gratitude to the colleagues from WZL-RWTH Aachen / Fraunhofer IPT (machine design pilot), for their contribution and support during this work.

References