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Manufacturing Systems: Skills & Competencies for the Future

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Abstract

Recent studies have presented clear evidence of the relationship between human capital qualifications and competitiveness. At the same time, there have been frequent reports on the shortage of skilled manufacturing personnel. This paper introduces some approaches to building skills and competences in manufacturing. The importance of human capital skills for industry's competitiveness is first discussed, providing an overview of the current situation in different world regions. Modern approaches to manufacturing education are shortly reviewed. The need for young people to be enlightened about the exciting character of manufacturing, with real life problems being addressed under business conditions, via scientific approaches and cutting edge technologies, is discussed. A "Teaching Factory" paradigm is being introduced as a distance-learning knowledge delivery mechanism of bringing the real factory into the classroom. The activities of the KNOW-FACT project aiming to deliver a pilot implementation of the Teaching Factory paradigm as a 2-way "learning channel" connecting industry and academia are further discussed.

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Keywords: manufacturing education; manufacturing skills; Teaching Factory

1. Introduction

Manufacturing, defined as the transformation of materials and information into goods for the satisfaction of human needs, is one of the primary wealth-generating activities of any nation [1]. Promoting excellence in manufacturing emerges as a strategic goal of both industry and society in the years to come. . The European Technology Platform for Future Manufacturing Technologies (Manufuture) has identified the *manufacturing education* as a major driver to achieving this goal [2]. In order to respond to this role, manufacturing education should follow new approaches so as to prepare industry for the next-generation innovation and the support of its growth.

Manufacturing education will be faced with major challenges in the years to come [3]. New skills will be required by the future "knowledge workers". Towards that direction, an adaptation of the training content and its delivery mechanisms to the new requirements of knowledge-based manufacturing is required. The manufacturing education should be concerned with the continuous provision of integrated engineering competencies and strong multi-disciplinary background. A manufacturing strategy focusing on digital business, extended production and virtual enterprises should be greatly considered. On the other hand, there is a growing need for the expansion of the technological aspect of education, with an extension to the 'soft skills'. On top of that, within a global environment, key manufacturing oriented actors, such as human resources and knowledge / information, should certainly become more international.

Engineers and blue-collar workers will need new life-long learning schemes to be assisted in keeping up with the pace of change. The rapid advancements in manufacturing technology and Information and Communication Technologies (ICT) have set on manufacturing education an intense requirement for a continuous update of the knowledge content and delivery schemes. The comprehension of the technical essence and the business potential of new knowledge /

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technology are essential for its smooth adaptation and integration into the industrial working practice.

The European manufacturing has been generally addressing significant challenges with respect to innovation, since it lacks in innovation activities. Although declining, there is still a significant innovation gap among the EU-25, the United States and Japan. The EU does lack in new ideas, however, is not so good at transforming them into new products and processes. Thus, modern concepts of training, novel industrial learning and knowledge transfer schemes can contribute to improving the innovation performance of European manufacturing.

On top of that, manufacturing is a subject that cannot be handled efficiently, only inside a classroom. The development of educational curricula has not kept pace with the growing complexity of industry, technology and economy. Research outcomes of educational institutions are typically presented to the scientific community without having been directly accessible to industry. Within this context, industry may not either comprehend or adapt to the technological advances in a direct way. Thus, the promotion of a novel approach to manufacturing education that would integrate education, research and innovation, emerges as a key challenge [2].

2. Skills and competences in the learning process

Skills and competences are major building blocks of the learning process (Fig 1).

"*Skill*" is one's ability to apply knowledge and use the know-how for the completion of well-defined tasks. Generally speaking, it identifies that an individual is able to do something within a specific context [4]. Skills may be cognitive (involving the use of logical, intuitive and creative thinking) or practical (involving manual dexterity and the use of methods, materials, and tools). In the context of a learning process, skills generally "evolve" across the following levels [5]:

- observation and replication of actions
- task reproduction from instruction or memory
- reliable execution independent of help
- adaptation / integration of expertise to meet requirements
- automated, unconscious management of activity

"*Competence*" is one's capability to (according to certain formal or informal criteria) handle certain situations successfully or complete a job. This capacity may be defined in terms of cognitive factors (e.g. different types of knowledge), intellectual and perceptual motor skills (e.g. dexterity), affective factors (e.g. attitudes, values, motivation etc.), personality traits (e.g. self-confidence) and social skills (e.g. communicative and cooperative skills) [6].

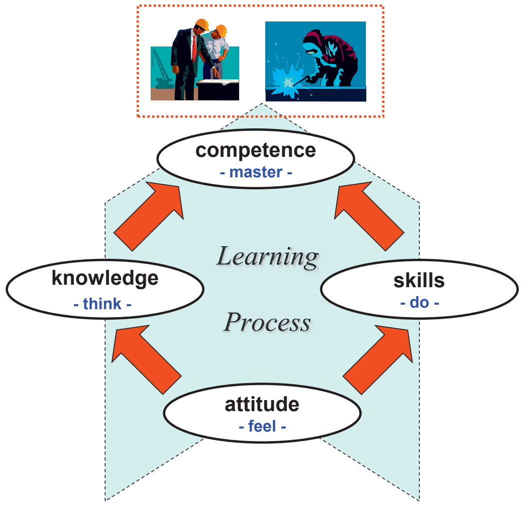

Fig. 1. The building blocks of the learning process

3. Manufacturing skills: Importance and status

The society is always appreciative of skills. Several studies have revealed the relationship between educational quality and economic growth, highlighting the fact that human capital is a key to growth. Indicatively, each year of schooling has been reported to boost long-run growth by 0.58 percentage points [7], while performance on international student achievement tests has been reported to have a powerful impact on growth (Fig 2).

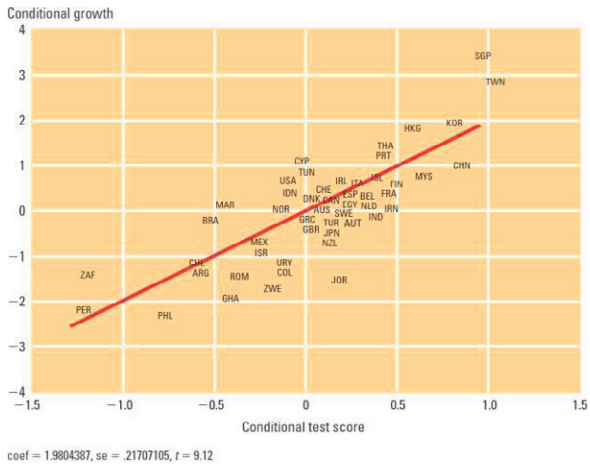

Fig. 2. Impact of test scores on economic growth

Skills contribute to the economic growth through two broad channels (Fig 3) [8]. When utilized effectively, skills can both raise employment levels and drive improvements on productivity. The impact of skills on employment, primarily through improvements on an individuals' employability, enables them to find jobs and to progress more easily in the labour market. In terms of improving productivity; at the broad level, skills enable workers to carry out more complex tasks, work more effectively, and produce higher value products. Adept workers generally are also better at adapting to changing conditions and requirements.

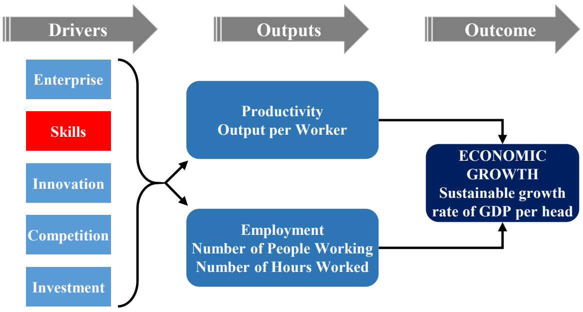

Fig. 3. Drivers of economic growth

Skills are critical for manufacturing as well. Studies have considered and validated "skills" as one of the drivers for manufacturing competitiveness (Fig 4) [9]. The availability of talented people, including scientists, researchers, engineers, and production workers, has been reported as the top ranked factor for manufacturing competitiveness. Coupled with the cost and availability of materials and energy, the three drivers are the "foundations" of manufacturing competitiveness, according to the manufacturing executives surveyed in this study.

Rank	Drivers	Driver Score
		10=High 1=Low
1	Talent – driven innovation	9.22
2	Cost of labor and materials	7.67
3	Energy cost and policies	7.31
4	Economic, trade, financial and tax systems	7.26
5	Quality of physical infrastructure	7.15
6	Government investments in manufacturing & innovation	6.62
7	Legal & regulatory system	6.48
8	Supplier network	5.91
9	Local business dynamics	4.01
10	Quality and availability of health care	1.81

Fig. 4. Drivers of global manufacturing competitiveness

On the other hand, skills shortages are reported to have a negative effect on innovation performance [10]. The Scottish Employers Skill Survey, in 2004, estimated that the inability of filling vacancies with adequately skilled workers, caused delays in the development of new products in 30% of the firms and difficulties in introducing new working practices in 24% of firms.

In 2009, the *European Union* had 38.1 million of highly qualified knowledge workers by virtue of both education and occupation [11]. On top of that, results of forecast studies show a considerable shift in labour demand, towards skilled workers, by implying that future jobs will become even more knowledge- and skills-intensive [12].

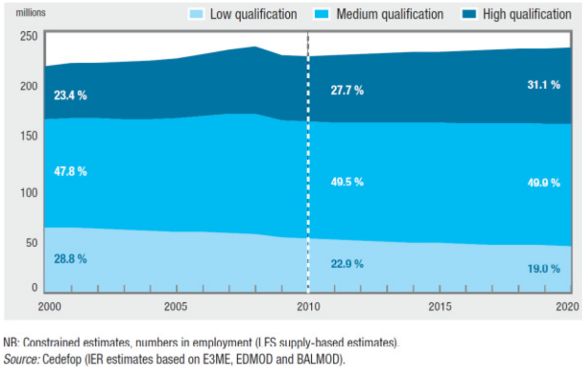

Fig. 5. Qualification level as a percentage of overall employment in Europe

Indicatively, the share of engineers among the Mechanical Engineering staff, in Germany, has more than doubled over the period 1982-2010, from 7% in 1982 to more than 16% in 2010, indicating that the skill level has increased considerably in the sector (Fig 6) [13].

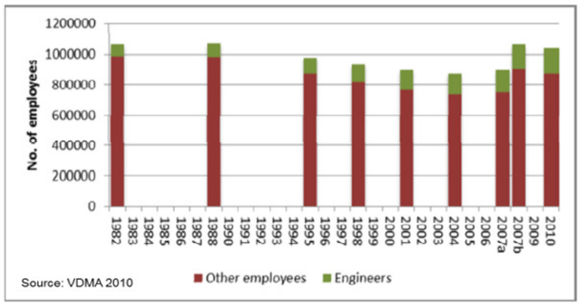

Fig. 6. Development of the of engineers in employment in Mechanical Engineering in Germany 1982-2010

A recent survey in Mechanical Engineering associations, reported in [13], has reconfirmed the forecasts about future skills shortages and gaps in Europe. Most of the associations were concerned about the bottlenecks in filling certain occupations/job functions in the companies (Fig 7).

The situation is likewise in the Unites States (US). While manufacturing stakeholders call for doubling the manufacturing's percentage of US employment to 20%, studies keep on reporting about shortages of skilled manufacturing workers even at times of low manufacturing capacity utilization [14].

Labour Sufficiency of supply Job type	Sufficient	No need currently	Scarce	Bottleneck
Machine operators			1,2,6,7,8	3, 5
Engineers	3,4		2,5,6	1,7
Reseachers/scientists	4		3,6	7
Production control/planning	4	1,2	3,7	5
Other qualified blue collar	3,7		1,8	
Management services, sales	1,2,3,6,7	4		

Source: Survey to associations in ME.

1: Fachverband Maschinen und Metallwaren Industrie, Austria; 2: European Sectoral Committee Compressors, Pumps, Valves; 3: EUROMOT; 4: Eurovent; 5: VDMA; 6: VDMA-FEM; 7: CECIMO; 8: Federation des Industries Mecanique (FIM)

Fig. 7. Short term demand and supply in Mechanical Engineering in Europe as perceived by industrial associations

At present, approximately three million job positions are open in the US, but such positions are not covered due to lack of qualifications [15]. The poor public image of manufacturing and manufacturing careers is considered being the main reason for this shortage. The poor image is due to a combination of factors:

- First, the largely outdated view of manufacturing as dirty, noisy and unsafe.
- Second, the belief that, for competent students, a university education offers higher income.
- Third, the belief that the US is a post-industrial economy, whose future is in services, software, and innovation and that manufacturing will be off-shored to the LLCCs (Low Labor Cost Countries).

China is currently the leader in the supply of skilled workers. Based on a survey by McKinsey Global Institute, it is estimated that by 2030, China alone will account for 30% of the world's new college-educated workers. This is the outcome of earlier investments in education [16]. Nevertheless, the strong increase in education levels has not prevented the increase in shortage and skill problems. Shortage of qualified staff is rated highest among 13 issues in the top business concerns of China [17].

In order to effectively address the emerging challenges of manufacturing education and skills delivery, the educational paradigm in manufacturing is required that be changed.

4. Teaching Factory: An emerging skills delivery mechanism for future manufacturing

The Teaching Factory has emerged as a promising concept of integrating the factory environment with that of the classroom. 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 integrate the learning and working environments, from which realistic and relevant learning experiences arise.

4.1. State of the art

In the last decade, the Teaching Factory concept has gained major interest, especially in the US, resulting in a number of educational and / or business pilot activities. At Cal Poly, the Teaching Factory makes use of state-of-the-art industrial grade production equipment, computer hardware and software [18]. It includes a) a functioning "real" factory hardware environment, and b) a production planning and control center to provide the decision making and communication functions, which act as an integrated whole, by utilizing state of the art communication networks. The activities of the Greenfield Coalition, a joint academia – automotive industry initiative, concentrate on a Teaching Factory, the Center for Advanced Technologies [19]. This "Factory as a Campus" environment combines a precision machining enterprise, producing car parts for GM, Ford, Daimler-Chrysler and their suppliers, state-of-the-art educational technology (Distance Learning, Interactive TV, Online Courses) and time-tested tutoring, mentoring, and lectures. In partnership with major semiconductor manufacturers, the Arizona State University East delivers an integrated educational program for workforce development built around a multi-use 1400m^2 Teaching Factory populated with late generation 150mm tools donated by Intel, Motorola and Microchip [20]. Industrial projects that take place in the Teaching Factory provide students with the integration of learning experiences into a contextual setting, where emphasis is given to competency and effective application. The Advanced Manufacturing Institute (AMI) at Kansas State University (KSU) operates a full service engineering and manufacturing facility, located at an industrial park [21]. The students involved provide services in designing and developing new solutions for industrial clients and complement their academic education with the hands on real engineering practice.

At conceptual level, an extended Teaching Factory paradigm, based on the knowledge triangle notion, has been suggested [22]. The aim is to effectively integrate education, research and innovation activities within a single initiative involving industry and academia. Moreover, [23] presented a manufacturing learning case study, based on a "virtual" Teaching Factory, communicated to the students through a variety of video clips. In practice, a number of pilot Teaching Factory facilities have been set-up and integrated into the education activities of academic institutions [24, 25]. Based on such facilities, several approaches for delivering skills to engineering students and industry practitioners have been defined and reported in the literature [26, 27, 28, 29]. An extensive survey and critical review of relevant applications in academic environments has been recently presented [30]. Teaching Factory facilities have been reported to be operating also in an industrial context, in order to provide hands-on manufacturing experience, which helps trainees apply problem solving techniques taught within their own organisations [31]. Some foresight works on the perspectives of the Teaching Factory paradigm have also been presented [32].

Most of the reported applications of the Teaching Factory paradigm simulate the key features of an industrial environment in an academic setting, using model production equipment. A drawback of these approaches is the fact that the dedicated production equipment, which is installed in the academic settings, can soon become obsolete.

4.2 A new approach to the Teaching Factory paradigm

Research, education and innovation are three fundamental and strongly interdependent drivers of the knowledge-based society. All three are referred to as "knowledge triangle". The idea of integrating the cornerstones of the knowledge triangle (Fig 8) into a single framework, in support of the manufacturing education, has given rise to an extended concept for the Teaching Factory [22, 33] (Fig 9).

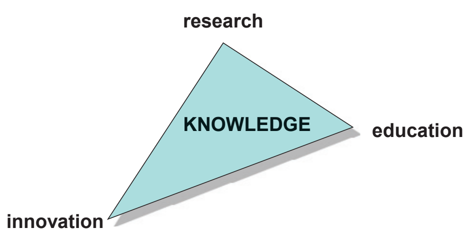

Fig. 8. The knowledge triangle in manufacturing

Based on the knowledge triangle notion, the Teaching Factory concept would become a new paradigm of both academic and industrial learning, having in fact, a hybrid mission:

- Engineering activities and hands-on practice under industrial conditions for university students
- Take-up of research results and industrial learning activities for engineers & blue-collar workers

The objective of the Teaching Factory would be to seamlessly integrate research, innovation and education activities into a single initiative, so as for the future perspectives of a knowledge-based, competitive and sustainable manufacturing to be promoted.

Co-operative research activities would be in the form of industrial projects or others, and could be addressing either technology application problems or technologically novel ideas. Industrial companies would provide knowledge having stemmed from their industrial experiences and practices, while the academia's contribution would be their scientific excellence. The research output developed within the industrial projects could be concurrently fed back to industry and academia.

The innovation activities would employ knowledge transfer schemes to keep industry, at the technological forefront, by supporting the continuous comprehension of the technical essence and the business potential of new knowledge and technology having derived from research projects. These activities would also support their smooth adaptation to and integration into the working practices as well as their fast "transformation" into innovation for the extended products of the companies.

The education activities would employ teaching / training schemes to communicate to students, new knowledge, business-like working methods, real–life industrial practice and an entrepreneurial spirit. Developing "problem solving" capacity as a core competence of future engineers would be a significant educational activity. That would be achieved by enabling young engineers to:

- practice theory
- observe problem solving techniques/methods
- learn to work in teams
- come in touch with real industrial problems/cases

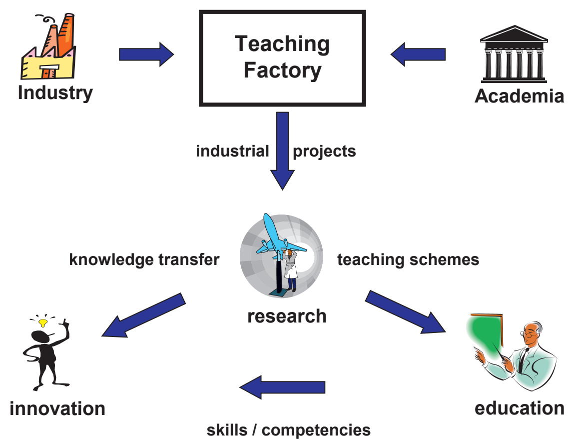

Fig. 9. The extended concept of the Teaching Factory paradigm

4.3 The KNOW-FACT project

Under the co-ordination of the Laboratory for Manufacturing Systems and Automation (LMS), a project called KNOW-FACT has been launched by a group of organizations, including FESTO, VOLVO, Politecnico di Milano, Technische Universitaet

Darmstadt, Tecnalia and CASP, in order to support a pilot implementation and validation of this Teaching Factory approach [34].

In the context of this project, the Teaching Factory has been defined as a 2-way "learning channel" (Fig 10) communicating:

- industrial practices to the classroom (*factory-to-classroom* scenario)
- "new" knowledge to the factory (*lab-to-factory* scenario)

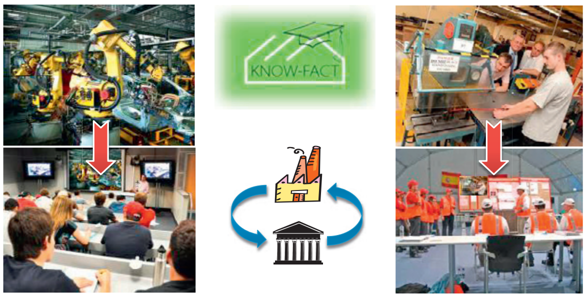

Fig. 10. The Teaching Factory as a 2-ways "knowledge communication channel" between the factory and the classroom

The project has so far focused on the definition and pilot implementation of the *factory-to-classroom* knowledge communication channel. The outputs of the relevant activities are analyzed hereafter. In turn, the *lab-to-factory* operational scenario will involve the use of physical didactic equipment as knowledge delivery facility, installed in an academic site. The aim is that this kind of facility be used as a test bed for investigation and experimentation with real industrial problems, resulting not only in didactic benefits but also in production innovation.

Within the *factory-to-classroom* setting, real-life operations from the factory are communicated to remotely located groups of engineering students coming from one or more universities. The factory and the academic sites are connected via internet, so that real-time communication is feasible, while no extra dedicated production facilities for training are necessary, since the actual facilities of the factory itself are considered.

Multiple layout options for the knowledge communication channel are possible. As depicted in Fig 11, the knowledge communication could indicatively follow either a "1-to-1" approach, that is, one factory to one classroom, or, a "1-to-many" approach, which involves one factory, interacting with many classrooms at the same time.

A modular configuration intended for the factory-to-classroom knowledge communication has been defined in order to allow for the necessary application and operation flexibility. The configuration considers multiple:

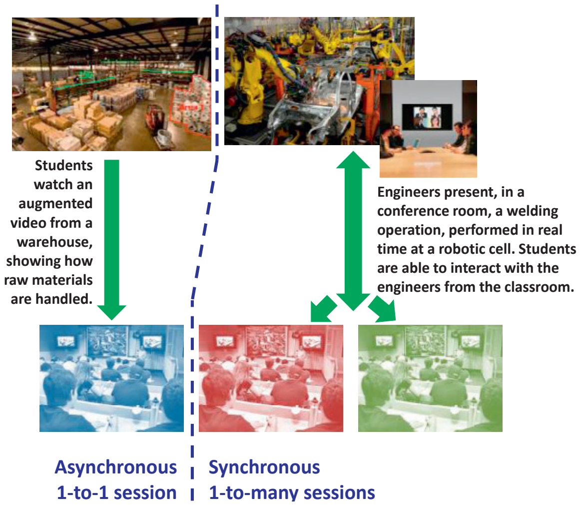

Fig. 11. Multiple layouts of the factory-to-classroom knowledge communication channel

- factory departments, production areas, facilities, or processes being the source of knowledge or problem to be addressed ("factory"),
- training subjects, being relevant to manufacturing science / technology, to be delivered through this approach ("study content")
- means used to communicating the knowledge and facilitating interactions between the factory and the classroom participants ("delivery mechanisms")
- information and communication technologies (ICT) used for the knowledge delivery ("delivery ICT technology")
- educational modules that accommodate the Teaching Factory based on training sessions within the standard engineering curricula ("classroom")

This modularity provides the necessary flexibility to address possible limitations resulting from the business and academic conditions under which the Teaching Factory knowledge communication channel will operate.

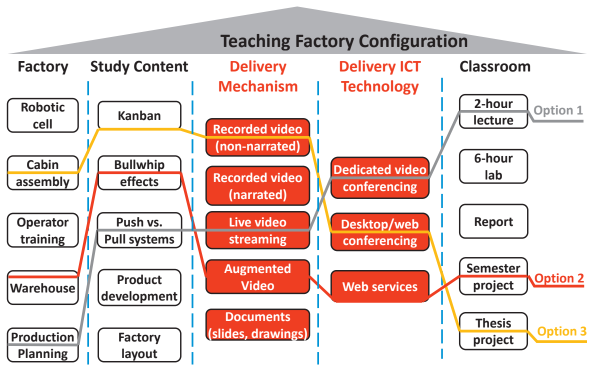

Fig. 12. Modular configuration of the factory-to-classroom knowledge communication

A generic ICT infrastructure has been specified in order to implement the modular knowledge communication channel (Fig 13). This infrastructure can be easily adjusted to accommodating the different set-up configurations, required for the support of each delivery mechanism. Interfaces have been defined in a way that different modules can be combined and create an individual infrastructure for the intended knowledge communication from the factory to the classroom.

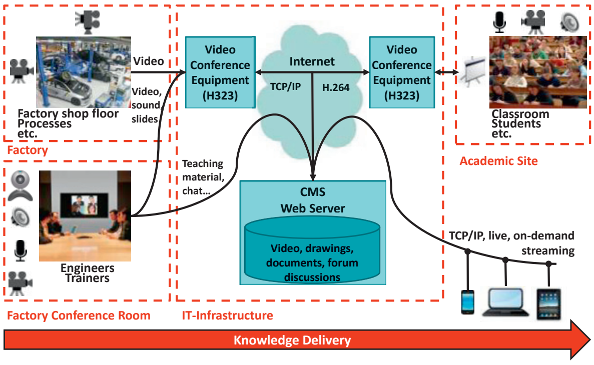

Fig. 13. Generic ICT infrastructure for the factory-to-classroom knowledge communication

An industry-driven pilot was launched to validate the implementation of the factory-to-classroom knowledge communication channel. A number of web-based live interactive sessions were launched between student groups at LMS and a group of engineers at a VOLVO factory. An actual industrial problem, related with process design activities of a new production facility within the factory, was introduced to the students. The students were requested to model and simulate the operation of this production facility and the related material flow. They experimented with the model and used statistical analysis methods in order to evaluate the results and come up with their own solutions and recommendations. From their side, the engineers provided the students with background knowledge, consultation and interim assessments of their outputs.

The outlook of the pilot has been very promising and far beyond the initial expectations from both sides. The students considered it as an exciting experience that gave them the opportunity to deepen their knowledge in certain topics and apply that in practice, while addressing real life problems, and working under actual deadlines and industrial practice terms. VOLVO engineers claimed that this pilot run of the factory-to-classroom knowledge communication channel provided them with ideas and options that would not have been considered under the standard company problem solving procedures. Several cases in which students demonstrated spontaneous talent and "out-of-the-box" thinking have been reported.

Conclusions

Skills have a major impact on the economic growth of a society, on the innovation process as well as on industry's competitiveness. In order for future challenges related with the supply and demand of manufacturing skills to be addressed, a change of the educational paradigm in manufacturing is required. The Teaching Factory approach, in view of this need, emerges as a promising new paradigm. This paper has introduced a Teaching Factory approach integrating the cornerstones of the knowledge triangle into a single framework. The activities of a pilot project, aiming to implement the Teaching Factory approach as a 2-way "learning channel", i.e. factory-to-classroom and lab-to-factory, have been reported.

Based on the outputs of the KNOW-FACT project so far, it is expected that the Teaching Factory paradigm can contribute in

- addressing the shortage of adept professionals, by improving engineering skills through curricula, based on technological innovation and knowledge delivery mechanisms in real life practice
- promoting the exciting character of manufacturing to the young people, enabling them to address real life problems under business conditions, with the use of scientific approaches and cutting edge technologies
- supporting the concurrent development of technologies and skills to improve product / process innovation and support knowledge-based manufacturing

Future work on the development of the Teaching Factory paradigm includes the definition of a Teaching Factory Network, by establishing learning and training channels, for the communication of manufacturing knowledge among multiple remotely located "factories" and "classrooms".

Acknowledgements

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