INNOVATIVE METHODOLOGIES AND DIGITAL TOOLS FOR HIGHER EDUCATION IN INDUSTRIAL ENGINEERING AND MANAGEMENT

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Abstract

The main goal of this paper is to present state-of-the-art as to the cutting-edge teaching and learning techniques and tools for delivering innovative higher education and training to the future generation of "knowledge workers". Starting from the best identified education experience, expected development of future digital tools for supporting and improving the learning experience is discussed. Tools, categorized for both hard and soft skills, required by the implementation of the Industry 4.0 concept are introduced. The paper describes how the Erasmus+ project 'IE3' tries to identify the most appropriate educational methodologies and tools for regular classes and innovative e-learning courses in industrial engineering and management (IE&M) for both university students and industry workforce. Finally, some examples from Italy, Poland, Spain and Sweden are given on how higher education institutions and industry work closer together in order to prepare learners how to handle the knowledge and training requirements related to the realisation of the Industry 4.0 concept.

Keywords: Innovative learning environments, digital tools for higher education, industrial engineering and management.

1 INTRODUCTION

There are different drivers society is enforcing as relevant elements that professionals and decision makers need to care about. Some of these drivers can be identified as sustainability, digital transformation, innovation and entrepreneurship. These dimensions become more and more relevant when specific threats like for example climate change can damage properties and the infrastructure, ending up with reduced productivity, inducing mass migration, etc. Sustainable value creation can significantly contribute to the deceleration of climate change and the reduction of negative economic impacts. Therefore specific manufacturing activities can be developed to promote a circular economy [1]. Over the past decades there has been an unprecedented development in digital information, communication and intelligent technologies and systems that significantly has influenced the quality of life on our planet. Innovation trends in complex computerization, digitization of manufacturing systems and process activities like cloud manufacturing (CMfg) emerge a novel business paradigm for the manufacturing industry, in which dynamically scalable and virtualised resources are provided as consumable services over the Internet. Manufacturing activities can now be understood as a service.

Such new paradigms are leading to the need for research, education, development and implementation of system solutions for optimizing, managing and diagnosing complex manufacturing industrial plants. In recent years Industry 4.0 has been the driving force and the heart of industry. Based on this and an analysis of the existing state-of-the-art in industry it is time to launch new research activities in order to prepare new multi-disciplinary professionals and university graduates to be ready to meet the demands articulated by the implementation of Industry 4.0 [2], [3]. The growing complexities of design and the need of efficient production practices have resulted in an evolution of new manufacturing methods to meet fluctuating market demands.

Finally, but yet important, the original concept "Open Innovation" was developed and validated in case studies of practice in industry. The activities carried out were more like an open system than the traditional vertically integrated mode [4]. New trends endeavour to develop rational, smart and sustainable products, which require new competences. Indeed, connected products offer exponentially expanding opportunities for new functionality, greater reliability, higher product utilization, and capabilities that cut across and transcend traditional product boundaries. In order to ensure technology is used effectively and efficiently, this shift needs to be shaped by educators. The impact of new

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technology will shape the way students learn, collaborate and engage in their education mode. Many universities have already made changes in their learning environments in order to encourage collaborative learning. Education 4.0 is a response to the needs of Industry 4.0 where the human work force and technology are aligned to enable new possibilities [5]. Mourtzis et al. suggest that advanced education can be called Education 4.0 and it will develop skills and build competences for the new era of manufacturing [6].

Education plays a key role in providing people necessary capabilities in order to be able to participate in the advancement of society, environment, and economy growth. With an increasing number of factors and stakeholders involved in the value creation, the manufacturing system becomes more complex, particularly with more conflicting issues related to the goals. In order to increase the efficiency and effectiveness of complex systems, industrial engineering has, since its formation, been associated with manufacturing. The subject area industrial engineering and management builds a bridge between technology and management, and is concerned with value creation aiming at specific goals through design and planning, operation and maintenance, as well as assessment and improvement. To accomplish the proposed improvements it is necessary to explore how the industrial engineering and management program at universities needs to change its content in order to response to these challenges.

The remainder of the paper is organized as follows: the goal and the methodology of the research is presented in section 2; the exisisting innovative technologies and digital tools for higher education in Industrial Engineering and Management (IE&M) are introduced in sections 3 and 4, respectively; conclusions of the work conducted are in section 5.

2 RESEARCH GOAL AND METHODOLOGY

The main objective of this paper is to evaluate and define innovative methodologies and digital tools for higher education in general and for industrial engineering and management (IE&M) in particular.

The research to identify the aforementioned methods for IE&M can be conducted according to the framework presented in Table 1.

Table 1.- Framework of research methodology

	Methods and tools implemented	*Expected results*
Identification of the innovative teaching methods offered by HEIs	Web search with predefined keywords (innovative teaching methods, conventional and unconventional teaching methods, teaching 4.0, education 4.0)	List of teaching methods offered by HEIs
Analysis of Education 4.0/Teaching 4.0. Identification of educational gap in terms of Industry 4.0	Literature review (definition, key words of Education 4.0, Teaching 4.0) and soft and hard skills required by Industry 4.0	Analysis of Education 4.0. List of soft and hard skills required by Industry 4.0
Industry 4.0 Educational model approach	Defining relevant teaching methods for Erasmus+ project ‘IE3’ classes and courses.	Teaching methods appropriate for Erasmus+ project ‘IE3’ for state-of-the-art in IE&M education

Erasmus+ project ‘IE3’ tries to identify the most appropriate educational methods and tools for both regular classes and innovative e-learning courses in industrial engineering and management (IE&M), for both university students and industry workforce.

3 INNOVATIVE TECHNOLOGIES FOR HIGHER EDUCATION IN IE&M

Through a preliminary analysis of the scientific literature on teaching methods in higher education, conventional and unconventional methods have been identified (see Table 2).

Table 2.- Division of conventional and unconventional teaching methods

Conventional teaching methods	***Unconventional teaching methods***
Lectures, Collaborative learning Case-based learning (problem-based learning, project based learning, inquiry based learning) Research based learning	Flipped classroom Interactive response system BYOD- bring your own device Learning by Doing Massive Online Open Courses Blended learning Augmented reality

Conventional teaching methods can be defined as activities that require face-to-face interaction between learners and teachers in the classroom. This type of teaching focuses on the role of the teacher. **Unconventional teaching methods** require the active participation of learners. The learners will learn through physical activities, demonstration videos, workshops and so on. These methods don't require face-to-face interaction and the lessons can be carried out remotely. The role of the teacher is not predominant [7]. In accordance with the definitions above, the following *conventional teaching methods* have been identified.

Collaborative learning occurs when there is a real interdependence between the group members in carrying out a task, a commitment to mutual help, a sense of responsibility towards the groups and its goals. According to De Hei et al. [8] collaborative learning is a teaching methodology that contributes to cognitive learning and is a teaching strategy in higher education, because it prepares learners for teamwork. The effectiveness of collaborative learning depends on how core aspects such as interaction, interdependence and individual accountability are designed and implemented. The design and the implementation depend on lecturers' belief about teaching and learning in general, and about collaborative learning in particular. In fact, teachers play an important role in collaborative learning to design and support collaborative learning activities but anyway they encounter difficulties in their classes. After the study was carried out the authors conclude by saying that to improve the benefit of collaborative learning, teachers need more support in the design and implementation of collaborative learning to translate knowledge collaborative learning into effective practice.

In a *typical case-based learning class*, the lecturer teaches course content, presents a case study and the class carries out an open case-based discussion. According to Harman et al. [9] case-based learning is a method based on problems and it is designed to create higher-order thinking. In the paper the authors support the idea that professions in dietetics are evaluated on credentials, interdependent education and practice. In fact, case-based learning can support learners to connect education and specialized practice. The aim of the authors was to examine students' perspectives of their learning after utilization the case-based learning in a nutrition course. Following the use of the case-based learning method in the course the learners acquired essential skills for their professional practice. Furthermore, the authors showed that this methodology will train the students for multi-faceted problems that they will run across in their future professional career.

Research-based learning (RBL) serves to promote student competencies associated to research practice. This approach implies the application of learning and teaching strategies that link research with teaching. According to Noguez et al. [10] the running of the course in RBL mode is the result of a careful analysis and design by the teachers. The authors emphasize the importance of involving the undergraduate students in research before starting their career.

An alternative to the conventional teaching method is the *flipped classroom*. In the flipped classroom the first step consists of autonomous learning by each learner. In the second step the classroom lessons' hours are used by the teacher to carry out a personalized teaching to put into practice the previously learned knowledge, where student collaboration and cooperation are central aspects. Consequently, the flipped classroom creates a reversed role between the teacher and the learners. O'Flaherty et al. [10] carried out a review of the scientific literature regarding the use of the flipped classroom methodology. From this review it emerged that it gives satisfaction to the students and the academic staff using the flipped classroom but a scarcity of conclusive tests that will help to build lifelong learning environments in university and post-graduate education.

Other authors have dealt with this subject, in 2015 Seery examined the rationale adopting the flipped classroom approach, how the educators have implemented the flipped learning into their practice and how these implementations have been evaluated. The analysis carried out by the author indicates that the approach is popular among students and educators who adopt it to develop an active learning environment, increase commitment and allow time to develop a deeper understanding of the discipline. This approach also allows for being implemented through a variety of strategies [11].

Based on the definition of *non-conventional teaching methods* the following teaching methodologies in higher education have also been identified through the study of scientific literature. The development of information and communication technologies (ICT) has allowed the emergence of teaching tools and providing practical tools to support education. The use of *interactive response systems* is increasingly common in university classrooms. Classroom Response Systems (Clicker) was the first type of "Personal Response Systems", but since it presented practical problems the Kahoot platform reached the market. This platform performs the same activities as the Clinker, but learners can respond using a device with Internet access. Ordieres-Meré et al. [12] show the effect of using gamification features as a motivation factor in education. The results of this study show that Kahoot is highly appreciated by students, who perceived it as a tool to improve learning and increase competition in the classroom.

The *Learning-by-Doing method (LbD)* has always been considered one of the most effective teaching strategies. In chemical engineering education the LbD method is the most common pedagogical tool. Dominguez-Ramos et al. [13] describe the application of LbD on undergraduate students in chemical engineering. From the teaching point of view, the LbD allowed the teacher to evaluate the transferable competences both internally and externally. The authors conclude that competences such as "Problem solving" and "Adaptation to new situations" have been positively developed. They therefore suggest extending the use of LbD as an educational tool because its benefits offset its costs by a wide margin.

Massive Open Online Courses (MOOC) appeared for the first time at American universities and the year 2012 is defined as “the first year of MOOC”. Luan et al. [14] analyse the salient features of the MOOC and subsequently discuss their applicability in engineering courses. MOOC education transforms the teaching process into a process of transforming knowledge information. Analysing engineering subjects, design and manufacturing are the main objectives. The advent of cutting-edge techniques requires continuous development and changes. From the point of view of the educational objective, the necessary qualities of engineering expertise are practical ability and the capacity for creating innovation. The impact of MOOC on the engineering education is enormous, but nevertheless it has not been able to replace the university campus since in addition to provide knowledge the university environment also cultivates the character of the learner.

Blended learning refers to the learning process where a learner learns both at a brick-and-mortar facility, as well as via online delivery. Other terms found in literature are: blended, hybrid, mixed, melted, technology-mediated instruction, or web-enhanced instruction. Blended learning can be grouped into several distinct models, and more are to come since experimentation and hybridization of models are constantly being developed [15]:

- *Face-to-face driver*: face-to-face teachers deliver the entire course; online learning in a learning lab is available as a supplement.
- *Rotation model:* within a given course students rotate between learning online at their own pace to learning in a classroom with a face-to-face teacher who usually oversees the online work; flipped classroom is a form of the rotation model.
- *Flex model*: an online platform delivers most of the curriculum; teachers provide on-site as-needed support through in person tutoring sessions or small group sessions.
- *Self-blended model*: students choose to take one or more courses online to supplement their traditional curriculum. Online learning is always remote, which distinguishes it from the online-lab model, but traditional learning is in a brick-and mortar institution. This model of learning is popular among high school students.
- *Online lab*: an online platform delivers the entire course, but in a brick-and-mortar location; students can also take traditional courses.
- *Enriched virtual model:* students work remotely while the teacher delivers the curriculum through an online platform; face to-face check-ins are optional.
- *Online driver*: an online platform and the teacher deliver the entire course; students work remotely and face-to-face check-ins are either mandatory or optional.

Riyami et al. [16] have built a hybrid training environment (face-to-face and distance) that integrates distance learning through MOOC (Massive Open Online Courses) learning platforms and classroom training, which is another example of blending learning. The hybrid model was proposed by the authors because the use of MOOC at the same time tends to integrate an online assessment system of a large number of learners in the education process. Since the MOOC teaching method concerns a combination of self-study and individual work, this integration of an online assessment system could lead to cheating or plagiarism that might distort the expected assessment outcome. The authors then propose a combined hybrid and evaluation method; a system of hybrid training and hybrid evaluation because effective supervision and constant commitment by teachers and learners are required.

The issue related to provide an adequate education to university students in order to bridge the gap that exists in the current state of manufacturing companies operating with advanced facilities is constantly under the magnifying glass. Makerspaces are spaces where members of an otherwise unaffiliated community can gather to design and fabricate digital and physical objects and systems. Over the last ten years, makerspaces have been created within communities, schools and businesses. Ferro dos Santos et al. [17] discuss if the companies can benefit from these projects and if engineer's skills can be developed in this environment. The authors support the idea that the makerspaces can be a great source of innovation if they are appropriately designed. The goal is to bridge the gap with professors, researchers, doers, start-ups and companies wanting to develop business-to-business practices. This paper identifies the potential of makerspaces as a strategic approach to teaching and learning in the fourth industrial era. In this context, the work conducted allows to understand the proper teaching model as well as to decide whether it is appropriate or not to invest in its learning environment. This will ensure that universities are educating professionals with the most suitable skills for industry and society, generating innovation in creative teaching and learning spaces.

Augmented Reality (AR) is a good teaching method for promoting students' self-employment since immersing the future engineer in real contexts and practices is essential. In this sense, AR allows new possibilities as it enables the combination of real and virtual words, increasing student autonomy and maximizing the time and resources available. Martin-Gutierrez et al. [18] have implemented several AR applications in order to improve different aspects and needs of students. The students are able to study the notes provided by the teacher, viewing the virtual contents associated with the notes via their mobile device. The virtual content associated with the notes is related to the work developed in the laboratory. Students feel comfortable about it and consider that the tools are easy, useful and handy according to the goal of the learning content.

4 DIGITAL TOOLS FOR HIGHER EDUCATION IN IE&M

Interest in industrial engineering as an educational discipline in higher education has grown steadily since 1901, when Diemer designed and offered the first industrial engineering course in the Department of Mechanical Engineering at the University of Kansas, US [19]. The roots of the profession "industrial engineering" date back to the second industrial revolution at the beginning of the 20th century. Frederick Taylor is acknowledged as the pioneering management expert, engineer and the leader of the engineering movement in developing methodologies for improved efficiency in manufacturing without using the term "industrial engineering" [20]. Engineering education as a field of development shares many characteristics of a discipline undergoing a scientific revolution as described in [21].

Universities frequently offer industrial engineering programs at bachelor, Master, and doctoral level. Universities are higher education institutions, where formal, institutionalized, and academic education and research work are performed since the model of higher education combines research and education. Students develop certain competences at universities for their future professional career, although knowledge is the outcome of the information assimilated and reproduced through learning. Knowledge can be configured as a body of facts, principles, and theories [22]. However, competence requires having skills and attitudes, and although the ambition is to provide such practical knowledge, there is not a well-established method available. Instead, different approaches are regularly used, like learning by doing, experiential learning, and virtual reality. Even worse, the academic courses are scheduled under a rather rigid schedule and scholars need to develop their own plans for their specific courses to fit into the existing rigid framework. Education and training systems, having remained static and under-invested for decades, are largely inadequate for actual new needs in terms of 4th industrial revolution [23]. The advancement of science and technology, especially in the next decade of Industry 4.0 which calls for the emergence of University 4.0, Education 4.0 and Teaching 4.0, requires the canvassing of a new focal point. In consonance with the changing landscape of higher education, the notion of a 'virtual university' surfaces as one of the preferred alternatives for the future [24].

In the last three decades, the focus of manufacturing systems has moved from efficiency to effectiveness. Efficiency is the extent to which time, cost, and resources are consumed in value creation activities. Effectiveness seeks to “do the right activity”. It is the capability of creating the intended value for mankind. Effectiveness must be learned, through training, and improved. While effectiveness questions the goal, efficiency stipulates the amount of resources and time, which are needed to reach the goal. To take full advantage of the opportunity created by advanced technology we need a similar revolution in education. It is said that universities need to forget the idea of separate disciplines like law or economics as the barriers between the subjects are hampering. Learners of tomorrow will need to understand how to deal with technology, have human skills such as empathy and innovation as well as critical thinking skills. Digital training can bridge the gap between university and employment. Curtin University focuses on being a “connected university”- joining people, processes and technology seamlessly. Block chain is as a potential tool to facilitate this as a secure global platform that could revolutionise training, collaboration, and accreditation.

Recently, there has been a growing sense that an opportunity for progress at the higher education level lies in the extensive research on different teaching methods that have been carried out during the last few decades. Most of this research has been on “active learning methods” and the comparison with the standard lecture method in which students are primarily listening and taking notes. As the number of research studies has grown, it has become increasingly clear to researchers that active learning methods achieve better educational outcomes [25].

Fumagalli et al. [26] illustrate the new proposal of Politecnico di Milano for the "Future laboratory factory" (FoFLab) promoted by joint research activities by Departments of Economics, Management and Industrial Engineering. FoFLab will initially focus on short-term research activities and will aim to become a key element for education on the future degree and post-graduate level, in order to foster the development of engineering students' abilities on intelligent production topics. FoFLab will therefore be a good test environment, among other activities, for physical experiments on modularity and development of plug-and produce paradigm.

The University of Rome “Tor Vergata” and the Dutch company Telpress International B.V. have launched an innovative initiative of educational tools called EIDUCO [27]. A new ICT tool was developed to manage the lessons more effectively (in-class) and support students in their studies (after-class). The EIDUCO tool was tested in the Industrial Plants course providing both frontal and online modes. To assess the effectiveness in terms of facilitating learning, students were given a questionnaire in the classroom. What has emerged is that (a) the system speeds up the study, (b) the system improves the quality of its study, (c) the system can be useful for distance learning, (d) the system is “very useful”, and (e) the students prefer EIDUCO to the traditional teaching method.

The FIT4FoF (Making our Workforce Fit for the Factory of the Future) project aims to meet the needs of workers, analysing the technological trends in 6 industrial areas concerning: robotics, additive manufacturing, mechatronics/machine automation, data analysis, information security and human-machine interaction. This project allows defining new skills requirements and job profiles and developing transferable education and training framework and tools [28].

NCBR (National Centre for Research and Development) introduced a program for dual studies at universities in Poland in order to promote collaboration between industry and higher education institutions. It is not a new concept in Poland since there are already dual study programs available. Since 2013 Poznan University of Technology in cooperation with Phoenix Contact Wielkopolska and Volkswagen Poznan run a practical training program in the field of automation and robotics. In 2014, more companies joined the project and dual training was also launched in the field of mechanics and machine design. There are also possibilities for Engineering Management students to participate in dual studies. The students work three days and study two days per week.

In Poland UNICollaboration [29] is a young, cross-disciplinary organization which aims to promote practice and research in virtual exchange initiatives for higher education. Virtual exchange is an innovative form of online learning which involves engaged learners in intercultural interaction and collaboration with classes at distant locations through online communication technologies under the guidance of teachers or trained facilitators. This method is also known as tele-collaboration, collaborative online international learning (COIL) and e-tandem learning.

In Spain Master’s programs focused on professional regulated degrees (architecture, civil engineering, industrial engineering and management, maritime engineering, etc.) have been developed in collaboration with the society sectors, building up professional “white books”. These “white books” have been used as a basis for course modules and main guidelines for course module syllabus. On the other hand, Master's programs not linked to professional regulated degrees can be designed with much more flexibility. Most of the Master's programs are taught in the national language and a few of them are run in English.

Each university develop their own approach to incorporate educational innovations, providing either a framework or some funding to support developments. In some cases [30] they have developed digital repositories to preserve the experience. The final responsibility inside the course is assigned to the set of teachers but, as far as the program is heavily regulated and accredited, significant changes requires the approval process of the accreditation agency, which lasts for at least one academic year. Another significant aspect is, in particular for private Master's programs related to the digital development, that relevant factors are not the syllabus per se but the image, including employability, and other factors like international reputation.

From the in deep analysis carried out by studying the national offer for IE&M programs in Spain it also appears that the gap between the technology itself and the education in management fails to integrate the tools provided by the new technologies for improving the managerial applications. Organizational design, for instance, is not discussed in general as a field to innovate. Standardization of formal communication, to integrate management issues between cyber physical systems and human workers, is also a field of potential application of technology to develop innovations.

Many higher education institutions in Sweden have established special centres in order to promote innovative pedagogic and didactic development and the usage of modern digital tools as a support for the educational staff to renew their teaching and training. At Linköping University such a centre denoted "Didacticum" was set up 2014. It main purpose is to the introduction and implementation of information and communication technologies in the institution's programs and course modules. Didacticum is organized as an administrative center. This means that Didacticum cannot employ people directly. Everyone working for Didacticum has their employment at one of the university's departments, even the director and the administrative staff. Didacticum can only recruit people from within the university, making agreements with heads of departments for shared employment. This means that most of the personnel at Didacticum are regular teachers with an interest in pedagogy and didactics.

The appointment procedure at Linköping University is aligned with the national recommendation that all teachers in higher education should have a basic pedagogical training of 15 ECTS credits or 10 weeks. In order to comply with this, Didacticum has a set of courses. One of these is "Becoming a teacher in Higher Education" (6 ECTS). The aim of the course is to increase standards and competence in academic teaching. In addition to more standard teaching skills, this also involves pedagogical reflection. Within the course there is the scope for the participants to reflect on their own pedagogical development and activities in relation to the course contents. In connection with this, participants will develop their own educational merit portfolio to better showcase their skills and progress in teaching. An overall theme of the course is how teachers can support students in their learning and knowledge development using both physical and digital tools. The course deals with and analyses how different theories of knowledge and learning are applied in different subject areas, how pedagogical perspectives may vary, and what the legal framework and conditions are that govern academic teaching.

In Sweden there are a lot of polytechnics offering one- or two-year dual education programs, like the Polish case, in close collaboration with the local industry and commerce. A big deal of the education time is spent at an assigned workplace where the learners can train hands-on what they have been taught in the classroom. These dual education programs will lead to a certificate and not an academic degree but the employment rate of having passed the programs is remarkably high.

5 CONCLUSIONS

Based on the analysis carried out, it is easy to see different innovative methodologies and digital tools for higher education that with different level of deployment could contribute to the realisation of Industry 4.0. What is of significant importance from now on is to create and design renewed and well integrated university programs and training courses with a learning environment characterized by innovation, collaboration and challenges both in relation to research and development but also, and perhaps most fundamental, in relation to the demands foreseen in the knowledge based industrial sector. The programs must rely on both national and international experiences and be prepared to change content and profile with a short notice. Different course modules in the engineering programs in general and in the industrial engineering and management programs in particular must also be available as lifelong learning opportunities for engineers already employed in the emerging sectors asking for updating of specific competences. Today there is also a growing interest in the CDIO model – Conceiving, Designing, Implementing, and Operating – in many modern management applications.

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