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TECHNOLOGY ENHANCED LEARNING FOR INDUSTRY 4.0 ENGINEERING EDUCATION

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The purpose of this paper is to analyze the main technologies of Education 4.0, which plays an important role in sustaining Industry 4.0 and has a significant impact on reshaping the engineering education itself. The concept of Education 4.0 is based on achieving a symbiosis between all educational actors: students, teachers, education managers and administrators in a common endeavour for improving the education practices. Education 4.0 designates educational settings, in which different actors co-create value at different levels. Encouraging the development and usage of intelligent educational infrastructure is essential for implementing the Education 4.0 concept.

1. INTRODUCTION

In the recent years Big Data, Internet of Things, Virtual and Augmented Reality, Machine Learning and other IT paradigms have become an integral part of the industrial value chain. This fast-growing process laid the basis for the next industrial revolution, called Industry 4.0. Being still a relevant topic for research, it sometimes causes ambiguity and disagreement when it gets down to the generally accepted understanding of the term as well as its principles and ways of implementation.

At the same time, an upcoming industrial revolution, Industry 4.0, with its coming consequent technology-driven changes, triggers engineering education to go through significant changes. Thus, it requires academics to modify the traditional engineering education. Considering the principles of Industry 4.0, the teaching staff has to enable their students to cope with Industry 4.0 and may be able to further investigate on the topic in conditions of life-long learning. In other words, it requires setting such tangible engineering skills both in processing and thinking that can apply to emerging technologies. This could be the knowledge and experience in virtual and augmented reality, automation, machine learning, robotics and model-based design.

In order to provide these new sets of skills, universities have to provide educational patterns that make it possible to combine technology, principles of modern industry, but at the same time it must be rooted in communication, be personalized, collaborative and relevant to society needs. Also, education needs new developing adaptive educational systems that would be enhanced using technology and Internet. Technology-enhanced learning offers such possibilities by providing support to teaching and learning process through the integration of e-learning and technology. It provides the access to socio-technical innovations on undergraduate and post-graduate level for both learning practices and research, considering the needs of individuals and organizations. Learning *with* technology can maximize the student academic experience in fast-growing areas of their interest about Industry 4.0 across all levels of global education.

The paper presents the main technologies of Education 4.0, which have a significant impact on reshaping the engineering education. The background section introduces the concepts of Industry 4.0 and Education 4.0. The third section describes the relevant methods and application of technology enhanced learning in engineering education. The next two sections identify the main drivers and barriers in adopting technology enhanced learning in engineering education and recommend solutions. The last two sections of the paper are Conclusions and References.

2. BACKGROUND

The so called 4th industrial revolution reshapes life, work and the way to relate to each other, while people strive to understand and benefit from technology changes. A challenge that is irreversibly transforming mankind, involving all actors from all economy sectors, regions, cultures worldwide, to keep the process human-centered.

Connectivity and networking of people from all over the world by the Internet and mobile devices, processing speed, access to knowledge, storage capabilities and the impact of disruptive and collaborative innovations in different fields such as: Internet of Everything (Internet of Things, Internet of People, Internet of Services, Internet of Data) [1], Virtual Reality, 3D printing, material science, nanotechnology, self-driving cars, artificial intelligence (AI), quantum computing, energy storage. Interdisciplinary approaches, "fusion of technologies across the physical, digital and biological worlds" [2].

Emerging business models make the circular economy in form of regeneration and preservation of natural environment necessary and new paradigms in our expression, entertainment influence our entire behavior. On one side, the emerging technologies develop exponentially and induce some uncertainty regarding how the transformations will evolve, on the other side all the actors of the globalized society - government, business, university and civil society bear the responsibility for understanding

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and creating a common view of the emerging trends. It is a matter of mentality, because sometimes decision makers are stuck in the traditional thinking, not willing to take risks, or not always recognizing the opportunity of these disruptive trends.

Starting from the concept of Industry Revolution 4.0, there have been coined some related concepts, like Industry 4.0, Marketing 4.0, Logistics 4.0, Work 4.0, ICT (Information and Communication Technology) 4.0, Health 4.0, Governance 4.0 [3] and Education 4.0.

The core elements of Industry 4.0 are: the prioritization of the future challenges relative to prosperity and quality of life [4], resources consolidation, promotion of innovation transfer and networking, strengthening of the dynamism of innovation in industry, creation of favorable conditions for innovation and transparency and participation through an innovation policy.

According to [5], there are nine trends in the Education 4.0: (a) *classroom-free learning* – meaning learning at different places and at different times, (b) *flexibility* – students modify their learning process with tools that are suitable for them, they will learn with different devices, programs and techniques based on their own preference (like blended learning, flipped classrooms and "Bring Your Own Device"), (c) *personalized learning* – the study tools are adapted to the capabilities of each student, (d) *mentoring* – students develop more and more independence in their learning process, so that professors as mentors become fundamental to student success and though the future of education seems remote, the teacher as a focal point in the information flow is vital to academic performance, (e) *practical application – curricula* will make room for skills that solely require human knowledge and face-to-face interaction and educational institutions will provide more opportunities for students to obtain real-world skills that are representative to their jobs, offering students to fulfill internships, mentoring projects and collaboration projects, (f) *project-based thinking, learning and working* – as careers are adapting to the future freelance economy, students have to learn how to apply their organizational, collaborative, and time management skills in shorter terms to a variety of situations, (g) *ownership* – students will become more and more involved in forming their curricula, with critical input from students on the content and durability of their courses, (h) *evaluation instead of examination – query and answer (*Q&A) are replaced by working in projects, (i) *data interpretation* - the human interpretation of data using human reasoning to infer logic and trends from these data will become a fundamental new aspect of the curricula. Industry 4.0 requires adequate skills for the 21st century. Some authors divide it into three categories (foundational literacy, competencies and character qualities) [5], others in four categories (according to [6], it is possible to aggregate and categorize competencies into four main groups – technical, methodological, social and personal competencies).

Especially in the field of engineering education, technology-enhanced learning is a valuable asset to learn about the concepts, which mostly appear abstract to the students due to the deductive teaching practices [7]. Some of the benefits of technology-enhanced learning in the engineering education are, according to [8]:

– the use of technology to deliver distance education surpasses barriers to learning, especially for the students with disabilities or female students with babies;

– virtual learning environments (VLE) provide assessment and evaluation of students and can be adapted to the learning style of each student;

– Technology and Engineering Literacy (TEL) is an adequate indicator for evaluating the student's skills for technology an engineering real-life use capabilities;

– learning materials are easy updated by professors, easy accessed by students through information and communication technology (ICT) and more and more an open access is provided;

– through ICT students can access experts in the technical field and discuss creative ideas and research issues;

– the mobile technology in training for engineering allows students to use their tablets in courses, or in their own locations, meaning in their own context. Technology-enhanced learning could be used for "gaming, virtual laboratories, international collaborative projects, real-time formative assessment and skills-based assessment".

Some of the main achievements of technology-enhanced learning in engineering education are: the quality of engineering formation on university and professional level, life-long learning and experience exchange across generations, interdisciplinary formation, risk aversion, entrepreneurial culture and innovation on the job [9].

According to [10], the systemic perspective, which will be mandatory in the future, asks for collaboration of multidisciplinary teams of technical experts and information exchange. The communication skills for engineers also need empathy and ethics, as well as understanding the best practices, in order to avoid repeating errors of the past.

3. METHODS AND APPLICATION OF TECHNOLOGY ENHANCED LEARNING IN ENGINEERING EDUCATION

Technology enhanced learning can be found in the engineering education in different implementation forms. Below, we are focusing on the remote and virtual laboratories, educational Robots, 3D virtual worlds, massive open online courses and e-learning platforms, with gamification and simulation facilities.

3.1. REMOTE AND VIRTUAL LABORATORIES

They became very present in engineering education [11–13]. They may be deployed into a free Learning Management System (for example, the Moodle platform). *Virtual laboratories* (VLs) represent a flexible method for practical activities for engineering education and most of them are considered to be web applications that offer the possibility to the students to reproduce the operations of real laboratories and to gain practical experience. Usually, students can access VLs anytime, from any location, being able to make the activities from the VLs as many times as they want. In general, VLs offer some options (like reporting templates) that help students and teachers to see and analyze the results and outcomes from the experiments. *Remote laboratories* (RLs) offer a virtual interface for a real physical laboratory. A major advantage of the RLs consists in the fact that they offer the possibility to an institution/company/firm that does not have high-tech equipment to realize specific experiments, working in the remote way (from distance) and use the equipment from another location that offers all the conditions to run and obtain the results for their experiments. Students can use the equipment and observe the running activities through a webcam, tablet, smartphone *etc*. Based on this approach, students will be able to access, observe, simulate and learn using professional laboratory instruments from any place and whenever is necessary. An advantage of the RLs is that they can reduce the costs of an institution/company.

3.2. EDUCATIONAL ROBOTS (ERS)

They are used in the educational process to improve and facilitate the learning activities and to improve the students' performance and results. Studies like [14–16] offer reviews of the applicability of robots in education, emphasizing the main advantages of their use. A specific category of robots is represented by those robots that are designed to support the teacher's activity in the class or/and to teach part of curriculum to the students. Several studies like [17–19] have shown that students become more engaged in the learning process (even for Science, Technology, Engineering, and Mathematics (STEM) subjects) after the use of this method.

3.3. 3D VIRTUAL WORLDS (3DVWS)

They represent useful tools for education, providing powerful support for collaborative work and socialization. They combine technologies and offer learning opportunities for many education types [20]. An example of a 3DVW that is also used for learning is ActiveWorlds (AW). AW is described by owners being "a sandbox platform for creating anything you can think of, inside a universe with hundreds of worlds, millions of objects, and a dedicated and friendly community" [21].

3.4. MASSIVE OPEN ONLINE COURSES (MOOCS)

They are online courses offered to an unlimited number of participants, having open access via the web. MOOCs are using online platforms that offer traditional materials (movies with lectures, readings, homework, tests, assessments, feedback) and interactive activities (blogs, forums). MOOCs provide courses in many education areas. In 2011, a new version of MOOCs appears, namely xMOOCs (online courses that follow a regular semester style). The first xMOOCs was an artificial intelligence course taught at Stanford University. In [22], the authors present the general trends and opinions of the stakeholders regarding the usage of MCCCs in engineering education.

3.5. E-LEARNING PLATFORMS WITH GAMIFICATION AND SIMULATION FACILITIES

They are systems that support the learning process through electronic technologies to access curriculum outside of the traditional classroom. Some of the advantages of these systems are: students can easily study from home, students with health problems can take online courses, the content can be accessed anytime from any location, the updated information can be seen by all the students in a very short time and so on and so forth. Game-based learning, also called the gamification, consists in the use of the game approach and design in different situations in order to engage students in the learning process and to motivate and to stimulate their action. A practical experiment where the game mechanism is presented [23], shows that the social gamification can be used to improve the students' performances in practical activities. Computer-based simulations provide students with the possibility to observe and experience real situations and scenarios. Based on this, it will be easier for them to assimilate and to combine the information with the knowledge that they already have. Regarding the engineering education, computer-based simulations (CBS) can complement, extend and in some cases to take place of the conventional elements. In [24], the author describes a computer-based simulation for the design project in an electrical engineering course. These educational platforms have led to a new learning concept, named flipped or inverted learning [25, 26]. The characteristics of this new way of learning is that the learning directives are provided though media files (video, pictures, text, animation) and the time spent by the students in class is mostly used for a better understanding of the course content, for discussing with teacher and peers, for debating and solving problems *etc*. In [27] it is proposed a combination of flipped and blended learning in order to enrich the learning process for engineering design courses.

The spreading of the technology-enhanced learning is supported by relevant developments in IT technologies, such as: virtual reality and augmented reality, complex data visualizations, linked open data, mobile and cloud computing.

Virtual reality and augmented reality. According to [28], they can be seen as an "emerging form of experience in which the real world is enhanced by computer-generated content". The reality is usually enriched with elements like audio, video, tactile information, graphics, GPS *etc*., in order to create to the user the perception of a real world. During the learning process, these technologies assist students to better and easily understand processes and remember taught information. There are many advantages of these technologies [29], such as: collaboration capabilities are improved, the learning process is becoming more practical, the learning place is safe, learning materials may be used anytime and anywhere. There are also some challenges using this method such as dependencies by the hardware, content portability issues.

Game-based learning (GBL). GBL represents an interesting method that is used very often also in software engineering courses [62]. The core of this method represents the game approach adopted in different situations. The players must explore several aspects of the game in an environment build by the teacher.

Complex data visualizations. Due to the huge amount of data stored into public and personal devices, several activities like (pre)processing, organizing and understanding have to be accomplished in order to extract the meaning of this data. In [30], there are presented different ways in which visualizations of complex data can be used as a method for support teaching, learning and assessment. The advantages of applying these technologies are: the stimulation of user's imagination, interactivity, usage of real images, trends identification *etc*. [31]

Technologies for linked open data. They allow interconnecting data with the possibility for the digital resources to be shared, reused, and accessed. As a result, the repository owners can publish structured data and establish categorized links [32].

Mobile computing, which allow the development of software applications to be used on personal devices. Some of these applications become more useful when the device on which they are installed can connect to a wireless network. Many mobile applications are made in order to help the educational process [33]. According to [34] these applications may present some issues like privacy, safety and student support.

Cloud computing becomes more and more used in education, in general, and also in engineering education, and in some cases is replacing the official learning management systems. The European Commission [35] promotes cloud computing as a solution for cost reductions and administrative efficiencies, but also it has raised the concern on data privacy and long-term sustainability.

Table 1 presents some areas of application for engineering education. For each area, one or several examples are mentioned in the last column.

Table 1

Areas of application and examples

Area of application	Technological approach	Examples
Self-learning and interactions	Remote and virtual laboratories	[36 – 38]
Improving the learning accessibility for students with disabilities	Remote and virtual laboratories	[39]
Education using robots	Educational robots	[15, 40]
Language learning	3D virtual worlds	[41]
Active Worlds 20	3D virtual worlds	[21]
Consumer psychology and behavior	Augmented reality	[42]
Science Learning (Chemistry, Medicine etc.)	Augmented reality	[43 – 45]
Interactive learning	Augmented reality	[45]
Visualization of educational data	complex data visualizations	[46, 47]
Mechanical engineering formulas; view, edit, and share DWG drawing file format	Mobile computing	[48]
Practicing engineering laboratory experiment Creative engineering	Mobile computing	[49, 50]
Unlimited stream of data	Linked open data	[51 – 53]
Data publication, consumption and reuse	Linked open data	[54]
Catalyst in Science, Technology, Engineering, and Mathematics (STEM) Education	Cloud computing	[55]
Chemical Engineering	Cloud computing	[56]
Engineering education curriculum	Flipped learning	[27, 57 – 59]
Enhance engineering communication and math skills	Gamification	[60, 61]
Software engineering and cyber-security	Gamification	[62, 63]
Practice simulator for engineering students	Computer-based simulation	[64]
Battery basics in laboratories	Computer-based simulation	[65]
Adapting higher education to the requirements of Industry 4.0 vision	Computer-based simulation	[66]

4. DRIVERS AND BARRIERS IN ADOPTING TECHNOLOGY ENHANCED LEARNING IN ENGINEERING EDUCATION

The technologies that can enhance learning in engineering education have a rapid development and usability. This was possible due to the spreading of IT technologies in society, in many areas of our life, including education.

An important driver of the adopting technologies is the financial problem of each educational institution (private or not). Having a limited budget, the management of these institutions tries to become more efficient from the expenses point of view, and also tries to create interesting educational courses and activities for the future students. The most common objectives of the management consist in having a high level of the student's satisfaction, a better retention rates, a good rate regarding the employability after they graduate, a good feedback from the employer's point of view, to follow the market demands and trends. Using technologies, many educational activities become possible without a very big investment from the institution part, for example remote and virtual laboratories, 3D virtual worlds, computer-based simulation *etc.*

The requirements for the students and other third parties are also increased. Most of the students pay taxes for their studies. In this context, during their engineering education (and not only) they want to benefit from attractive and useful courses and activities. In the Education 4.0 perspective, an important role is played by the personalized learning [67]. In that respect, using technologies in the learning process will be easier for the institutions to put the student in the middle of this process and to better understand student's needs. Having enough information about the student, a large number of educational programs and instructional approaches may be created. The student may choose what he or she thinks it is more representative and important for him.

Using several technologies in the learning process may offer a more interesting experience to the students. From this point of view, another important driver for using them is the interconnection and integration of the several used technologies into bigger and more complex systems that provide to the students with the opportunity to use several technologies at the same time. Enhancing the learning process using technologies for engineering education supposes in many cases to store data in local databases or in cloud, to use a specific software and hardware, to be connected to the Internet or intranet. Having each technology with its own particularities, putting and using them together in a single system represents an important challenge for an institution.

Virtual laboratories (VLs) are eliminating the risks associated with the physical presence in a real laboratory and with the use of real elements/components. The activities may be done anytime and from anywhere. This allows students to analyze different systems having very low programming knowledge, change the mathematical model or build a new model based on new requirements. VLs represent an investment, because even at the beginning some money must be spent in order to create the VL, even though, for the long term, the costs will be reduced. In [68] there is described a VL from UNILabs open course. The simulation windows of this VL consists in three sections:

menu (with buttons: files, control, language, step stime), a system 2D for graphical representation and control (with four tabs: controls tab, PID tab for setting some parameters, controller tab, AC signals tab), and the evolution graphs and indicators.

In [63] the authors have conducted a survey that shows the fact that the Game-based learning (GBL) for cyber-security was very efficient during the training process. The survey has analyzed four cyber-security computer games, that were developed to educate social engineering, secure online behaviors, and 10 cyber-security first principles. The conclusion of the authors regarding the use of this method was that it is a very good platform to teach cyber-security principles and secure online behaviors for high school students.

Adopting technology to enhanced learning in engineering education comes with benefits, but also meet some barriers that affect their implementation, such as [69]:

The lack of knowledge and expertise in using and adapt them to the educational activities requirements. Some of them might be too complex or hard to use for some teachers or students [70].

The lack of adequate tools. In [71] it is stated that there are not enough tools to understand the effect of these technologies on the education practices.

Data privacy concerns. By using such amount of data and such complex educational systems, data privacy might become an issue for educational institutions. Policies regarding this aspect must be very well designed, build and applied.

The requirement for combining different technologies, in order to achieve the best results for the learning process. This could increase the complexity of the learning and teaching environments.

The speed of renewing technologies can lead to adoption resistance, mainly from the teachers' side.

5. SOLUTIONS AND RECOMMENDATIONS

The use of the technologies for enhanced learning in engineering education (and not only) depends on some factors, like management decisions, the material support that each institution has, how easy is to adapt the *curriculum* (or at least a part of it) to be taught by using one or several technologies, how open are the teachers and students to use these technologies, the inputs from the stakeholders in order to create the environments that will be created and simulated using emerging Education 4.0.

Management decisions influence somehow the material support of the institution, and both are related to the budget of the institution. Increasing the level of money spent in educational technology will create the framework for adopting the technologies, but a very important thing is how these technologies are used to support teaching and learning activities.

For a technology to be used, there has to be way that it has to be adapted to the *curriculum*. In this case, the teacher must to do supplementary efforts for creating a context in which the technologies are well integrated and support indeed the learning process and teaching activities.

Because most of the technologies are already used in the market by stakeholders from the industry, a good collaboration between educational institutions and them will have a big impact in adopting these technologies by creating simulated environments, experiments and pilot programs to deliver value for all partners.

6. CONCLUSIONS

In the Education 4.0 vision, the learning process is much related to the learner and his needs, taking into account also the personalization of the learning process. The learner must to take decisions regarding his education, and for doing this he must search the answers for questions like "what?, why?, where?, when?, and how?", while moving forward during the learning process.

In this context, the adopting technologies for enhancing learning in engineering education can be a very good solution to create the framework that the student needs [73, 74]. Taking into account the aforementioned questions, the technologies offer answers and alternatives for most of them (for example: delivery methods for the educational content, teaching approach, collaborative work, knowledge enhancement, location (on campus, at home, at work), industry requirements, job specific knowledge *etc.*) [75].

The technologies, along with their specific methods for enhancing learning in engineering education, represent a big step forward for the education process [76]. A new interesting and complex approach of the learning process is build, this approach being associated with specific strengths (education become more accessible and personalized according to the student's needs, reduce the costs, perform educational activities anytime and anywhere), weaknesses (creating inadequate environments and applications to work with, some technologies are too complex to be adapted to the *curriculum*), opportunities (combine several technologies in order to obtain better results, identifying situations that are very hard to reproduce in real life) and threats (the incompatibility between technologies, data privacy issues).

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