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THE EVOLUTION OF INDUSTRY 4.0 AND ITS POTENTIAL IMPACT ON INDUSTRIAL ENGINEERING AND MANAGEMENT EDUCATION

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The paper analyses both technical (hardware and software) and managerial elements (management and enterprise culture) of Industry 4.0 related to their potential impact on Industrial Engineering and Management Education in particular, as Industrial Engineering and Management programs are tied up to the industry in a stronger way and are thus more sensitive to innovative changes in the industry. The paper also offers a case study by authors in various European countries, during the restrictions caused by the COVID-19 pandemic, by questioning two professional categories of particular interest to the field of analysis: teachers and students. It also analyzes their position on the inclusion of the Industry 4.0 element in IEM engineering programs in both the technical and management fields, concerning the hardware, software, management and organizational culture elements.

1. INTRODUCTION

The last decade showed a rise of the concept Industry 4.0, regarded as the 4th industrial revolution [1] through the introduction of automation, internet of everything (internet of things, of people, of services and of data) [2] and artificial intelligence in industrial manufacturing processes. Their impact on education is debated and concepts like Education 4.0 have appeared and are being used in scientific papers [3, 4]. The paper aims to analyse the last trends in industry in their technical and management dimensions, as well as their potential for Industrial Engineering and Management Education from the point of view of two major stakeholders: the professors and the students. Thus, the paper answers questions like: are industry 4.0 related concepts like education 4.0 just a temporary trend or is the potential impact long-lasting? If yes which are the components that should be more present in Industrial Engineering and Management Education?

2. METHODOLOGY

The paper relies on the methods of qualitative research in accordance with the exploratory aims targeted by it [5]. Therefore, a case study about the potential impact of Industry 4.0 in Industrial Engineering and Management (IEM) Education is used connected with the instruments of the case study method: the survey and the observation [6, 7]. The empirical research was embedded in two surveys – one for professors and one for students, on multiple topics done with the support of the European Professors of Industrial Engineering and Management (EPIEM) and the European Students of Industrial Engineering and Management (ESTIEM). The professors sample consisted of 41 professors from five countries (Romania, Austria, France, Italy, Portugal) from which 27 answered the Industry 4.0 related questions. The students sample consisted of 229 students from nine countries (Romania, Austria, Germany, Bulgaria, Belgium, Turkey, Serbia, The Netherlands, Portugal) from which 132 answered the Industry 4.0 related questions.

The respondents answered the following questions on a scale of 1 to 10:

1. The importance of adding software related Industry 4.0 elements in the curricula;
2. The importance of adding hardware related Industry 4.0 elements in the curricula;
3. The importance of adding management related Industry 4.0 elements in the curricula;
4. The importance of adding enterprise culture related Industry 4.0 elements in the curricula.

The analysis of the responses is done with simple univariate methods, that show the distribution of the answers on the scale of each Item.

3. LITERATURE REVIEW

When analysing engineering education and scientific papers about it, we observe that it is going through a lot of changes, some of them being triggered stronger due to the pandemic context, that imposed the exclusive or predominant use of online teaching in many countries. Web-based solutions were promoted as a good solution before the pandemic context [8], based on their enhanced visualization modelling options and visual learning potential [9, 10]. Such solutions are supported by proven results in achieving better learning outcomes [11] thus confirming the previous identified e-learning potential [12] and, being utterly needed as the only possible solution after the breakout of the SARS-COV-2 virus when classrooms shifted to online teaching.

One of these identified trends could lead to the use of Industry 4.0 learning environments [13] as well as to the integration of Industry 4.0 contents and methods in the curricula of IEM Engineering. The analysis of this potential impact is linked to the evolution of Industry 4.0, which is encompassing next to mechanical and software innovations also new management and organizational approaches, including aspects of organizational culture [14]. Thus, all

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these areas should be analysed both regarding the innovations implemented within Industry 4.0 as well as regarding the need of introducing such elements in IEM education.

4. TECHNICAL RELEVANT ELEMENTS OF INDUSTRY 4.0 (HARDWARE AND SOFTWARE) AND THEIR POTENTIAL FOR IMPROVING IEM EDUCATION

Industry 4.0 has the focus on automation, big data and artificial intelligence (AI), which relates to a potential shift towards online teaching, as was inducted by the SARS-CoV-2 pandemic, in which most of the schools and universities around the world have closed their campuses indefinitely and the swift switch to online learning was considered the only valid option for the safe continuation of the curriculum.

Moreover, this industrial revolution brought along the implementation and/or discovery of quite a few technological substitutes of what it was once believed to be the only way for information to be passed along in the means of IEM. One of the most important substitutes is the Virtual Laboratory (VL) which attends to the need of practical experience in the field of engineering without requiring the same amount of time and economical resources for setting up the space and construction [3, 15]. Moreover, the VLs are also equipped with Virtual Reality (VR) technology which perfectly simulates different optimal environments for specific tasks, projects, or scientific reactions.

Another substitute, or enhancement, is represented by the Robots, which can play different roles in education. The robot as a programming project: in various studies, researchers have concluded that students often neglect their academic accomplishments since they cannot physically see the effects of their changes and innovation. Therefore, proactively programming and changing the resources and limits of a black box can help not only with the development of skills and the raising of the GPA, but also with students' self-esteem. The robot as a learning focus, refers to using a physical robot to solve an actual issue [16].

As software plays a relevant role in programming robots

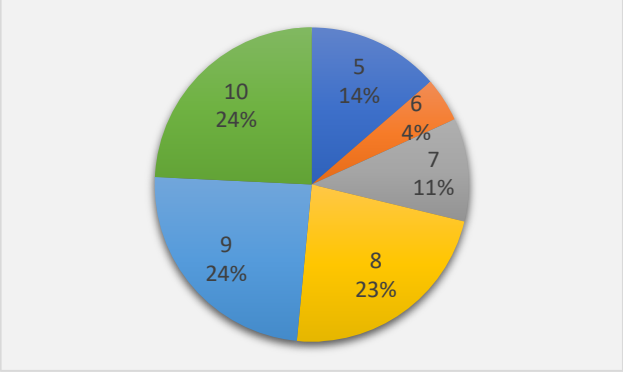

Fig 1 – The importance of adding software related Industry 4.0 elements in the curricula perceived by the students on a scale from 1 (min) to 10 (max). *N*=132 respondents.

and training AI units, the students were asked about the importance of introducing software related Industry 4.0 elements in their curriculum. The results presented in Fig 1. above show that a vast majority of 95 % is for the introduction of such elements with ratings on the higher half of the scale (6–10) with a predominance at the highest end of the scale 24 % perceiving maximum importance (10), and approximatively similar percentages for the next two importance levels (8 and 9) , while only 5 % are indecisive (rating the importance at 5 – the middle of the scale) and none voted in the lower part of the scale (1–4).

The importance of introducing software related Industry 4.0 elements in the curricula resulting from the answers of the responding professors converged with the results from the students' survey, only being a little more cautious: 89 % were perceiving a high importance (6–10) from which 26 % a maximum importance (10) and in total 67 % of 8 or higher. 4 % where indecisive rating the importance at 5, while 7 % gave an importance rating of 4 and none rated it lower (1–3).

As the academic party has encountered during the pandemic, platforms have become the new Manuals, Books, Notebooks, BlackBoards, all focused into one application sustained by different technologies and each University has had direct access to its own (or, better yet, its own and its partners) giant data base. The content can be accessed remotely at any time and from any location, requiring only an electronic device such as a smart phone or laptop. These platforms also provide a shared notebook in which all participants can add information available to everyone. This tremendously helps students from any fields from Engineering to Management, for brainstorming especially, while also polishing skills such as communication and teamwork.

The benefits of adopting technical components into the standard education system (present up until spring 2020 are) in hopes of enhancing it are vast, but the barriers of its implementation should be taken into consideration, as well.

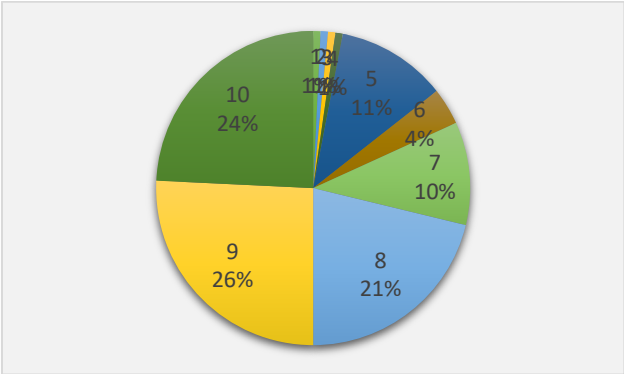

Fig 2 – The importance of adding hardware related Industry 4.0 elements in the curricula perceived by the students on a scale from 1 (min) to 10 (max). *N*=132 respondents.

Another technical aspect of Industry 4.0 that can be introduced in education would be about hardware related Industry 4.0 elements. Students asked abouts its importance perceived it predominantly as high 85 % (rating the importance 6-10) with most of them at maximum (10) 24 % or in the following importance levels 26 % (9) and 21 % (8). 11 % were indecisive (rating the importance at the middle of the scale) while 4 % gave importance rating in the lower half of the scale (1–4).

The professor's survey was like the students' survey also regarding the importance rating of introducing hardware related Industry 4.0 elements in the curricula: 88% rated it in the higher half of the scale (6–10), while 4 % were indecisive (rating of 5) and 4 % gave a low rating (2 %

rating it 2 and 2 % rating it 4).

The convergence of results between the two groups is not surprisingly as both students and professors share the aim of good educational results converging with the demands of the labour market. The extra caution of the professors is also understandable because they must also consider the challenges that result when facing the introduction of new courses in the curricula.

In order to have a successful transition to the Industry 4.0 Education, responsible parties should assess the level of expertise and knowledge in the use of tools, perhaps address the issue by providing an optional training course.

Moreover, the physical tools should also be thoroughly verified, and everyone should possess a means to connect to the said platforms or programs used by the academic institution he/she adheres to.

5. MANAGEMENT RELEVANT ELEMENTS OF INDUSTRY 4.0 AND THEIR POTENTIAL FOR IMPROVING IEM EDUCATION

According to [17], the fourth industrial revolution could determine a “powerful engine of innovation” for the next period. At the same time, Industry 4.0 will require a connection between CPS (Cyber Physical System) in both production and logistics, but especially in terms of "Internet of Things" and "Internet of Services". CPS systems will be found in the form of Smart Factories through intelligent machines, intelligent storage systems or intelligent supply chains, which means that in the specific education of engineering and management, improved information is needed in these areas. Production management must be open to improvements in industrial processes, especially in the horizontal value chain, by integrating vertical processes manufacturing. Built-in horizontal systems must be integrated with vertical business processes (sales, logistics and finance, etc.) to allow better management of the entire manufacturing process.

One of the components of Industry 4.0 refers primarily to the digitization and vertical and horizontal integration of the value chain, from product design and procurement to production, logistics and service. Engineering and management as an educational system must therefore provide essential information related to the process through efficiency indicators, or methods of quality management in real time. Even if the digitization of the products and services offered means new intercommunication devices, they must be known by future engineers due to the new methods of data collection.

However, in terms of digitizing the business model and customer service, here the management component has priority. There is a need to extend course materials to understand new complete digital solutions on digital platforms. Digital business models are focused on providing complete services and optimizing customer access and interaction with them [18].

New engineering managers must be prepared to meet the growing demands of customers and to solve various problems in companies.

As the research shows, in Fig 1 we can identify a large percentage of students interested in elements related to the implementation of information about Industry 4.0 at the management level. This percentage of positive importance ratings are very high, namely 37 % for the maximum score (20), respectively of almost 80 % for the scores over 8, and 88 % giving a rating in the higher half of the scale (6–10) reveals the fact that regarding the managerial information transmitted to the students, there is a need to modernize it with information about Industry 4.0.

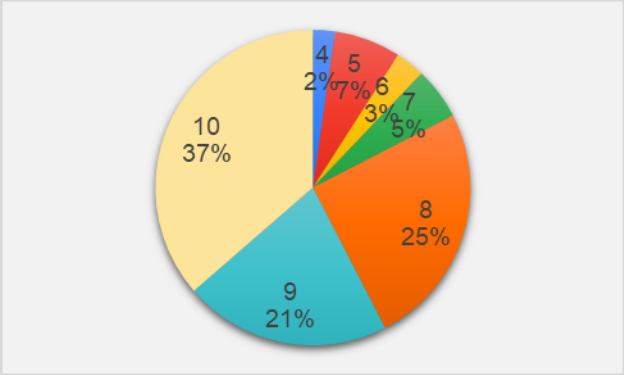

Fig 3 – The importance of adding management related Industry 4.0 elements in the curricula perceived by the students on a scale from 1 (min) to 10 (max). *N*=132 respondents.

Professors were also showing a high rating with 70 % rating it 8 or higher and 85 % rating a high importance (6–10). 7 % are indecisive (5) and 8 % rate a low importance (3 or 4). Here we see a similar convergence of importance rating from the side of the professors like we could see in the rating of technical Industry 4.0 with the same caution caused by a group that is also in charge with the implementation of the new elements.

Management must identify digital methods to quickly identify and eliminate downtime from production, use labor at full capacity, store information in real time, or quickly identify and intervene in the event of defects through ERP (Enterprise Resource Planning) systems [19]. Therefore, IEM education needs to be oriented towards ERP systems. One of the biggest challenges of Industry 4.0 is data, which is not only generated at an astonishing rate, but is quantitatively generous. These data present different challenges and require new methods of storage, processing, and management. Then, another challenge is the availability of this data for various analyzes and their security. Solving them allows decisions to be made on current data in real time, by using smart sensors, without which the concept of Industry 4.0 would not be possible. In this sense, the implementation of sensor technologies and the training of students in this direction is a necessity.

According to [20], flexibility in production in a cost-effective way is essential, especially in the automotive field. To provide the necessary flexibility, the production environment should be adaptable to the process.

Besides the technological investments and the connection with existing ones, one important element is the comprehensive understanding of the customer. Thus, IEM education must adapt marketing courses to the knowledge of their needs through new marketing strategies and data analysis. The concept of mobility is fundamental for improving time, reducing costs and promoting customer-producer communication at all times. Then, managerial decisions will be made based on data analysis. The digital revolution in industry is generating another major goal: the ability to get more and better data to support strategic decision-making. Strategic coherence can be possible only through the analysis of the results and environments, basic elements in modern management.

The heart of Industry 4.0, which makes up the business model, in conceptual terms, is the Smart Factory. The basic principle of a smart factory is to deliver productivity far beyond expectations. This is possible by bringing together all the technologies that provide the best methods and techniques for the production process. Moreover, because Smart Factories are not just intelligent machines and robots that communicate through an advanced software system, higher education in engineering and management must show how people and production are interconnected through an intelligent work environment. Smart Manufacturing reduces the amount of waste and inefficiency by using for example Radio-Frequency Identification (RFID) tags, Near Field Communication (NFC) or RFID tag, which does not require a proximity of the scanner, and this leads to productivity. All these elements should be integrated into IEM-specific matters.

A production line within Industry 4.0 is the incorporation into the production lines of Cyber Physical Systems (CPS), which can receive information on customer orders directly from the Enterprise Resource Planning (ERP) system that is connected to the Cloud to make it possible to verify in real time the production status. Thus, the production line becomes flexible and makes it easier to produce different orders, using different resources, without the need to organize separate production lines. IEM students need to know this information and the benefits of implementing CPSs in intelligent production. A new way to address failures or avoid their occurrence by switching to fixed-before-brake systems, which can greatly improve the life of a product and the costs of maintenance.

Another necessary concept that should be introduced in the courses of IEM students is the value chain of production, as shown in Fig. 1. It refers to the sequence of activities through which an organization turns inputs into outputs and ultimately sells, delivers, and continues to support these results for customers. From the perspective of Industry 4.0 objectives (Fig. 1), in any type of production there are four main management objectives: productivity, risk reduction, incremental income and new income. It is necessary that elements subordinated to these categories will be found in the curricula of all IEM specialists, because they define the tactical approaches for managers.

In terms of improving production, there should be a focus on maximizing equipment use, minimizing downtime, increasing efficiency, managing supply networks, synchronizing costs, and making clear plans.

However, in terms of digitizing the business model and customer service, here the management component has priority. There is a need to extend course materials to understand new complete digital solutions on digital platforms. Digital business models are focused on providing complete services and optimizing customer access and interaction with them [18].

Risk reduction can be one of the necessary subjects to deliver information about the supply of raw materials in logistics, price maintenance, guarantee insurance, and risk assessment by geographical areas. Efficient business development places management in a position to effectively control existing revenues and opportunities. Thus, students should identify new sources of income, to understand models of increasing income flows, to develop projects focused on the client and on strengthening the relations with them. Creating new products, expanding markets or new mergers or attractive acquisitions can be considered important opportunities in terms of the objectives of this Industry 4.0.

Industry 4.0. is therefore a way of transforming the industrial environment, which incorporates all existing elements that lead to increased productivity, reduced costs, focused production on a single segment, increased product variety, customer orientation, and helps to interconnect production with the environment, business to streamline human-machine-information system communication and lead to better communication.

6. ENTERPRISE CULTURE OF INDUSTRY 4.0 AND ITS POTENTIAL FOR IMPROVING IEM EDUCATION

The benefits Industry 4.0 has to offer from technical point of view have been mentioned in the previous chapters, however it's important to understand the role of the enterprise culture of Industry 4.0 and its potential on improving IEM Education. According to [21] enterprise culture is an essential factor for the success of a business system, one of the purposes of Industry 4.0.

Enterprise culture "is a pattern of values, norms, beliefs, attitudes and assumptions that may not have been articulated but that shape the ways in which people in organizations behave and get things done" [22] The enterprise culture by forming behaviors of employees is the one that leads to a community of shared values, mission and vision [23, 24].

To implement the methods of Industry 4.0 in a company, the most suitable culture is the innovative one because enterprises with such a culture have a smoother transition to Industry 4.0 [24]. The innovative culture of a company refers to the freedom of employees to suggest solutions to various problems in a creative way, to take a chance on new opportunities even if it might be risky, all these leading to an entrepreneurial mind-set within the company. The employees work in an environment where trust is present, and information sharing is encouraged by the organizing teams.

The employee's training and learning activities should respect the Industry 4.0 required competencies like flexibility, result-oriented, data-analytics, IT, and knowledge about human-machine interaction [24].

The application of the Industry 4.0 is possible mostly in enterprises with high supportive and innovative culture. Therefore, SMEs find it easier to scale up while for the more rigid bureaucratic state companies the transition to Industry 4.0 is much slower.

It is obvious that to prepare employees for facing Industry 4.0 challenges, the education providers need to adapt their methods by using emerging technologies to allow students to learn by doing, in order to become agile and flexible, to poses excellent communication skills and also to be skilled in "advanced analytics, Internet of Things and digital security" [25].

Education is now supported by AI portals that are adapted for individual learning pace - the teachers and students do not need to be in the same room anymore, and, they have access to a higher number of electronic resources [26]. By offering interactive and personal content, universities prepare IEM students to be competitive in the work market [27]. One of the priorities of education providers during the last year was to train professors to use

the best digital technologies tools to provide a quality distance education.

Thus, the distance education developed like never before and forced professors to adapt their teaching methods to this new paradigm. Slowly, during the last year more and more students benefited from AI technologies education leading to a greater interdisciplinary of teaching [25].

The students and professors that answered this research survey faced the outbreak of the COVID-19 pandemic and were forced to move all the activity online.

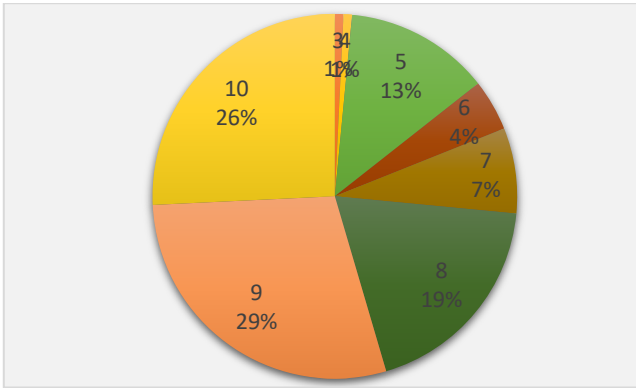

Fig 4 – The importance of adding enterprise culture related Industry 4.0 elements in the curricula perceived by the students on a scale from 1 (min) to 10 (max). $N = 132$ respondents.

The students' sample revealed a high importance regarding the introduction of enterprise culture related Industry 4.0 elements for 85 % of the responding students (rating 6–10) while 74 % had a rating of 8 or higher. 13 % were indecisive rating the importance in the middle of the scale (5) and 1 % rated the importance low (1–4). Ratings resulting from the professors' survey were similar 7 % low (1–4), 7 % medium (5) and 86 % high (6–10) where 70 % were 8 or higher.

104 Romanian students answered the question *How important would be the addition of enterprise culture related Industry 4.0 elements in your curricula?* They were asked to choose a value between 1 and 10 and *the* overall average result was 8.17. Students from other countries responded as well and their answers resulted in an average of 7 for Netherlands, 8.33 for Serbia, 9.5 for Portugal, Greece and Austria 10, Bulgaria 9.5 and Belgium 9.33.

The same question was applied in the research on 20 Romanian professors and the the overall average result was 8.25.

Professors from other countries responded as well and their answers resulted in an average of: 9 for France, 6.5 for Portugal, and 6 for Italy.

This result shows that both students and professors in Romania are aware of the skills students need to have to be competitive in the work market. This has to do with the fact that in Romania the Industry 4.0 is present by the development of the IT sector and by the government support in financing tech start-ups.

7. CONCLUSIONS

The results of the research point out that both analysed stakeholder groups: professors and students present a very favourable position regarding the inclusion of Industry 4.0 element in IEM engineering curricula in both technical and management area including hardware and software elements as well as management and organisational culture elements.

Most of both groups speaks for integrating Industry 4.0 elements in existing courses: 84.6 % of the professors and 65.5 % of students. A part of them also supports the creation of new courses shaped especially for Industry 4.0 specific content: 38.5 % of the professors and 53.4 % of students.

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