IMPROVING ENGINEERING EDUCATION IN THE INDUSTRY 4.0 ENVIRONMENT. THE USE OF AN EDUCATIONAL INNOVATIVE LAB

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Abstract

The Higher Technical School of Mining and Energy Engineering of the Technical University of Madrid is working on the transformation of an educational laboratory to improve educational issues on Industry4.0. It is an experience-oriented to the education of new engineers, that will evolve professionally in an Industry4.0 environment, through the implementation of the Educational Innovative Lab concept.

Industrial revolutions have always meant a big change in all sectors. Industry 4.0 brings new aspects and innovations that companies must incorporate to remain competitive. The new engineers being educated today will need to broaden their knowledge, not only having to be knowledgeable about their sector but also needing innovative knowledge.

Educational Innovative Labs are an opportunity to prepare these new generations of engineers in the skills and capabilities demanded by 4.0. These will be the same skills that companies will demand to remain competitive and relevant in the industry. Therefore, these laboratories are conceived to allow future professionals to expand their knowledge and learning more practically through the use and integration of new technological tools for industry.

This paper describes an educational project that is being developed as part of the development of the MEITIM Project with the support of EIT Raw Materials, one of the eight Knowledge and Innovation Communities (KICs) initiated by the EIT (European Institute of Innovation and Technology), funded by the European Commission, and whose mission is to help boost the competitiveness, growth, and attractiveness of the European raw materials sector through radical innovation and guided entrepreneurship. In this paper, implications derived from the Industry 4.0 concept and innovations are described, to show how the Educational Innovative Lab helps students to acquire and develop skills and knowledge addressed to this competitive environment.

The development of a highly-skilled workforce in an Industry 4.0 environment through the use of Educational Innovative Labs is aligned with the efforts to shift the European competitiveness and employment by encouraging and promoting innovation and entrepreneurship in students.

Keywords: Faculty development; Program development; Engineering studies; Innovation; entrepreneurship skills; Innovative Lab; Industry4.0.

1 INTRODUCTION

The fourth industrial revolution is completely shaping the industry and the society in these first decades of the 21st Century. Like other industries, the mining sector is being deeply transformed to become more competitive and cost-effective [1]. The global mining industry is currently facing more competitive economic settings and increasing requirements and responsibilities for health, safety, and the environment [2]. The terms “Industry 4.0” [3], “Mining 4.0” [4], or “Mine of the Future” [5] are being widely discussed.

The minerals industry is facing a changing talent landscape. With digitization necessitating new skillsets and with technology cycles that are getting shorter and shorter, the new panorama is transmitting pressure in the need for a trained workforce, and mining companies need to ensure that their boards and staffs are properly constituted to support the transformations that the sector is currently undergoing, including fluency in such areas as technology, integration, systems security, and cybersecurity [6].

In the raw materials sector, technology is not an end in itself. The greatest impact will come from embedding these technologies as an integrated whole and all across the mining value chain. Each opportunity is significant in itself but achieving the full potential of all opportunities is possible only if they are pursued in an integrated fashion [7].
This requires deep knowledge of the potential impact and value of digitalization on mining and metallurgical processes [8]. But it also needs trained people, able to take advantage of this revolution, with the necessary creativity to imagine new solutions and the entrepreneur skill that will allow them to go ahead in setting up these new ideas and solutions [9].

EIT Raw Materials is one of the eight Knowledge and Innovation Communities created to boost innovation and entrepreneurship across Europe with the support of the European Institute of Innovation and Technology (EIT). Created in 2015 and participated by more than 120 European partners from leading industries, universities, and research institutions from more than 20 EU countries [10], EIT Raw Materials is the largest consortium in the raw materials sector worldwide. Its partners are active across the entire raw materials value chain, from sustainable exploration, efficient mining, and mineral processing to substitution, recycling, and circular economy. It has the vision of developing raw materials into a major strength for Europe by finding new, innovative solutions to secure supply and improve the raw materials sector in Europe and the mission of contributing to boosting competitiveness, growth, and attractiveness of the European raw materials sector via radical innovation, new educational approaches and guided entrepreneurship [11].

The Raw Materials Academy is the overarching brand of all the educational activities of the EIT Raw Materials. Activities across the entire ecosystem of learners (Ph.D. students, masters’ students, industrial partners, professionals within the raw materials sector, and wider society) foster new ways of learning and teaching by connecting academia, industry, and research organizations. EIT Raw Materials will educate people that will have an intra- and entrepreneurial mindset and will be able to develop their functions in new working environments, fostering the entrepreneurial and innovation skills, knowledge, and attitudes needed for the entre- and intrapreneurs of tomorrow.

While the raw materials industry is focusing on digitalization and automation, but also on how to implement concepts like Industry 4.0, technology integration, smart mines, etc., no MSc program in technology integration for the development of professionals needed by the industry exists. There are many initiatives regarding different technologies and their application to mining, but nothing regarding how to focus on this issue from a strategical point of view of a company, converting this integration into a competitive issue [7]

Supported by the EIT Raw Materials through the Raw Materials Academy, the first international Master’s program in Entrepreneurship, Innovation and Technology Integration in Mining (MEITIM) is being developed (http://www.meitim.eu) to fill this gap. This MSc level program will be oriented to:

- Enhance the creativity and innovation capacity of engineers.
- Provide in-depth knowledge of technologies (by practical training) that are entering the primary sector of the raw materials value chain (geology, mining, mineral processing, and metallurgy).
This will give them the ability to understand the technical, business, social and economic aspects, as well as giving them a broad understanding of innovation and entrepreneurship in the raw materials sector.

- Stimulate technological innovation and technology integration with the vision of creating new opportunities and added value.
- Improve the mindset of entrepreneurship.
- Expand the KIC community of professionals in this dynamic and innovative activity sector.
- Complement the T-Shape profile of professionals trained.

By achieving all this, the program will train the engineers that can successfully develop the technology integration projects that currently are taking place in the raw materials sector.

This project started beginning in January 2020 and will finish ending December 2023. It is being developed by a consortium coordinated by Universidad Politécnica de Madrid (Technical University of Madrid) from Spain and constituted by Agencia Estatal Consejo Superior de Investigaciones Científicas, CSIC (Spanish National Research Council) from Spain, Atlantic Copper S.A.U. (Spain), Geologian tutkimuskeskus, GTK (Geological Survey of Finland), Lappeenranta University of Technology from Finland, Metso Minerals Oy (Finland), Outotec (Finland) Oy, Politechnika Wrocławska (Wroclaw University of Science and Technology, WUST) from Poland and Suomen Malmijalostus Oy (formerly Terrafame Group Oy) from Finland.

This paper describes the preliminary results of the concept application and development of an innovative lab as part of the teaching infrastructure to be used by MEITIM at the School of Mining Engineering of the Technical University of Madrid. It also describes how EIT Raw Materials is supporting this kind of initiative.
2 METHODOLOGY

Development of mining technologies corresponds to the abovementioned targets and is based upon the implementation of modern information technologies (IT and IoT) into design and production processes of mining operations, results of interdisciplinary research in the fields of extraction and consumption of mineral resources, industrial automation, and environmental protection. Modern mining companies are capital and technology-intensive, complex industrial systems, technological processes of which are equipped with facilities worth tens of millions of dollars. A significant share of mining enterprises is considered hazardous industrial facilities. Combined with the escalation of international competition and drastic rates of technology development, it leads to rising requirements towards the quality of labor resources (especially engineering professions), needs for continuous improvement of knowledge, skills, and competencies [6].

“The European Green Deal” [12] was established to set a new growth strategy aimed to transform the EU into a fair and prosperous society, with a modern, resource-efficient, and competitive economy, becoming the world’s first climate-neutral continent by 2050 [13] (this means there are no net emissions of greenhouse gases in 2050) and where economic growth is decoupled from resource use. The strategy sets how this sustainable use of resources, together with an improvement of human health, has to be achieved by promoting and investing in the necessary digital transformation as an essential enabler of the changes.

The transition to climate neutrality [14] is an opportunity to expand sustainable and job-intensive economic activity but, as the transformation is taking place at a too slow pace with progress neither widespread nor uniform, the European Green Deal will support and accelerate the EU’s industry transition to a sustainable model of inclusive growth. Those who move first and move fastest will hold a greater competitive advantage. Achieving a climate-neutral and circular economy requires the full mobilisation of industry. It takes 25 years (a generation) to transform an industrial sector and all the value chains.

The “New Industrial Strategy for Europe” [13] adopted in March 2020, addresses the twin challenges of the green and the digital transformation [12] as both will require new technologies, with investment and innovation to match. They will create new products, services, markets, and business models. They will shape new types of jobs that do not yet exist which need skills that we do not yet have. And they will entail a shift from linear production to a circular economy. The breadth and depth, the scale and speed, the nature and necessity of the twin transitions are unprecedented. For this, the European industry cannot afford to simply adapt it must now become the accelerator and enabler of change and innovation. This is why the new industrial strategy is entrepreneurial in spirit and action.

The “New Circular Economy Action Plan” [15], together with the industrial strategy, will help modernise the EU’s economy and will stimulate the development of lead markets for climate-neutral and circular products. Energy-intensive industries, such as mining, steel, chemicals, and cement, are indispensable to Europe’s economy, as they supply several key value chains. The decarbonisation and modernisation of this sector are essential for Europe.

To become more competitive as it becomes greener and more circular, the industry will need a secure supply of clean and affordable energy and raw materials. Stepping up investment in research, innovation, deployment, and up-to-date infrastructure will help develop new production processes and create jobs in the process. Ensuring the supply of sustainable raw materials by diversifying supply from both primary and secondary sources, is therefore one of the pre-requisites to make this transition happen [12]. EU industry needs ‘climate and resource frontrunners’ to develop the first commercial applications of breakthrough technologies in key industrial sectors by 2030. Europe needs to revolutionize the way we design, make, use, and get rid of things by incentivising our industry.

Digital technologies are a critical enabler and present new opportunities for attaining the sustainability goals of the Green Deal in many different sectors. At the same time, Europe needs a digital sector that puts sustainability at its heart. Europe needs to ensure that digital technologies can accelerate and maximise the impact of policies to deal with climate change and protect the environment, improve energy efficiency, and circular economy performance.

As the industrial requirements change at a rapid pace due to the drastic evolution of technology, the necessity of quickly investigating potential system alternatives towards a more efficient manufacturing system design arises more intensively than ever.[17]
A competitive industry depends on recruiting and retaining a qualified workforce. Pro-active re-skilling and upskilling are necessary to reap the benefits of the ecological transition. As the twin transitions gather speed, Europe will need to ensure that education and training keep pace. Making lifelong learning a reality for all will become even more important: in the next five years alone, 120 million Europeans will have to upskill or reskill [14]. This reflects the importance of skills for the twin transitions and the opportunities they can create for people.

The term Mining 4.0 encompasses many concepts and purposes, the first advances being the incorporation of greater adaptability, efficiency, flexibility, and individualization of the industrial manufacturing processes that make up the value chain to meet the needs of customers in today's mining industry market. It consists of interconnecting all the parts of a mining company, leading to effective automation and a smarter mine. So it is the set of technologies that allow the digitization of mines and raw materials industries, positioning them in the digital age, digitizing all production processes based on information technologies, increasing productivity, competitiveness, and a more efficient organization of the productive means, that is, the set of techniques that automate production by providing information in real-time to the managers, so that they can make decisions by interconnecting the different sections. Accordingly, it is a twist to the use of new technologies, since the main common aspect is the digitization of the industry, in which the virtual and the real part are united to improve performance [17].

In this new industry, mining and industrial processes require high connectivity between their components without giving up the basic requirements of business continuity and high availability. Therefore, it is necessary to create new intelligent manufacturing processes capable of better adapting to needs, production processes, and efficient resource allocation [17]. Much of the value creation in mining will no longer be based on the efficiency of operations to move material, but rather on how well companies collect, analyze and react to real-time information to separate and transport material more efficiently [18].

The mining industry is confronted with many technological challenges along the entire production value chain. There is a need for innovative production solutions [19]. The evolution of computers, sensors, data analysis, and intelligence techniques will allow for the strengthening of the integration of automated processes within the mining industry. Therefore, it can be said that in the future mining will be almost robotized and operations will be largely remote. In this way, the optimization of processes will be done in offices with experts analysing data and studying different models. In short, digitalization and automation will be increasingly relevant [17].

To be truly innovative, companies need a workforce with a culture that supports new ideas and new ways of doing business efforts, but also execute those ideas [20]. It's a question of experimenting, piloting, learning, and adapting to developing solutions. Involving the workforce in any new technological developments through both on-the-job and classroom-based training can have a radical impact on the successful implementation of new strategies [20]. World-leading mining companies have embarked on substantial training programs to upskill their workforce to enable them to handle a rapidly changing operating environment [22].

Many of the world's largest companies have developed some form of an innovation lab. Innovation labs are a form of specialized offices dedicated exclusively to innovation, idea-generation, and free-thinking, with the most innovation-centric culture possible with the mission of think outside the box, throw ideas around and be as innovative as possible [20]. Most of the innovation labs are already facilities that are oriented to research activities for researchers and Ph.D.’s, but not for students. These laboratories have become an almost predetermined framework for collaborative innovation, so many companies have one, as it is a good way to explore new technologies and ideas. Besides, an innovation lab spans organizational, sectoral, and geographic boundaries and seeks to involve all stakeholders in problem-solving activities. On the other hand, innovation labs have the mission to serve as a focal point for innovation programs and activities [17]. Most of the existing innovation labs are facilities oriented to research activities for researchers and Ph.D. These facilities have not been conceived as laboratories for students.

The majority of the existing innovative labs are facilities oriented for research activities and the use by researchers and Ph.D. students. They have not been conceived as education labs for students in Graduate and MSc programs. This project focuses on the development of this concept to help in the learning and training of a new generation of mining engineers, especially in the new skills demanded by companies [20].

The concept behind the Innovative Labs can change and adapt, as these laboratories can help in the learning and training of a new generation of engineers, in this case, mining engineers. For these new
generations of engineers, these facilities can help them acquire the skills demanded by the companies. In a broad sense, an innovation lab is a physical space dedicated to the creation, development, and execution of ideas. It’s a space to cultivate, share, and grow not only potential earning opportunities but also relationships within an organization [17].

3 RESULTS

Future graduates of the MEITIM program will face and contribute to the creation and adaptation of new ways of designing, projecting, building, communicating, or relating to others, as well as the emergence of new professions and new business models. The use of Educational Innovative Labs contributes to the creation of the competent workforce of the future by complementing the educational methodologies helping to educate future professionals that will be able to be innovative and agile in a market that is constantly changing.

Educational Innovative Labs as defined in [20] contribute to providing a complementary opportunity to students to learn and put in practice a series of skills that will be needed by the new professionals, and which are the following:

- Deep disciplinary knowledge.
- Creativity and open mind when analysing problems and possible solutions.
- Strong personal and interpersonal skills, leadership, innovation, entrepreneurship, and collaboration.
- Strong research, design, and development skills.
- Good problem-solving skills.
- Able to integrate diverse skill sets and best practices.
- Capacity to oversee and standardize processes.
- Capacity to coordinate an increasingly interdisciplinary team.
- Able to focus on developing new ideas to improve products as efficiently as possible in the process and trying to achieve the best total cost.
- Have professionalism, great communication skills, and ethical responsibility.
- Capacity to apply the technical essence of mathematical, scientific, and engineering knowledge.
- Capacity and flexibility to apply knowledge in a specialized technical and/or professional area.
- Capacity to design and conduct each experiment, analyze and interpret field and laboratory data in various areas, thus being interdisciplinary.
- Capacity to identify, formulate, innovate, and solve engineering problems.
- Ability to communicate effectively by listening, observing, speaking, and writing correctly.
- Capacity to participate and to lead multidisciplinary teams.
- Good knowledge of the elements, methodology, and principles of system design, project management, advantageous financial management, business fundamentals applied to the private, government, and non-profit sectors, and public legislation and administration fundamentals.

Our students will be the new workers of tomorrow and must be prepared to do their job as well as possible, without any limitation that prevents them from developing in any professional environment.

4 CONCLUSIONS

The education of the new generations has evolved due to the new developments introduced. Despite this, it is important to defend the integration of disciplinary and practical knowledge along with personal and interpersonal skills [17]. The engineers of the future must be educated to be the workforce that will conceive, design, implement, and operate the projects of the near future. They will work in constantly evolving environments and through technology and innovation, they will be able to seize opportunities by learning differently with new skills and broader knowledge [17].
New ideas must be produced, and through a creative culture, this may be possible. Many elements help prepare the space for innovation and guide it in the right direction. These include location (there is greater prosperity when students are far enough from the organization and close enough to test and co-create with the teams involved in implementation), team time (students need a long, uninterrupted time to think and create with fewer meetings), excursions (by visiting people in the field it is possible to inspire the team), language (words are an important part of defining expectations on a daily basis), values (taking into account the values of the laboratory and people allows to open minds and formalize a dynamic and diverse culture), the rituals (through small victories the idea of slow progress is avoided), to learn from failure (failure is allowed as part of learning process so that people take the necessary risks to drive innovation), storytelling (it is important to have a shared narrative with the parent organization) and space (it is about differentiating from the corporate matrix giving rise to collaborative and direct areas to go deeper into difficult problems, involving people more) of innovative lab.

The use of an Educational innovation lab contributes to providing training to students who will be the next generation of engineers and who will have to integrate technology, develop new ideas, and execute projects. In this way, the innovation lab serves as a bridge to move from innovative thinking to execution, fostering a culture of continuous improvement by:

- Empowering students to accelerate the adoption of emerging innovations.
- Create a culture more conducive to innovation and informed risk-taking.
- Help students develop institutional capacities so that innovation is more strategic and systematic.
- Show students that innovation labs developed by companies aim to create new sources of revenue or strengthen existing ones by improving productivity or speed.

Therefore, an educational innovative lab will be a place that provides facilities to cultivate new ideas and help develop an inquisitive perspective. In this way, they involve students in innovative and creative activities to launch new ideas and innovations through creativity, and the different skills that they will need to face future challenges. Thus, these creative pedagogies would be incorporated through innovative labs promoting and retaining talent [20].

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