DEVELOPMENT OF INNOVATIVE LABS FOR EDUCATION IN MINING ENGINEERING PROGRAMS

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ABSTRACT

The School of Mines and Energy of the Technical University of Madrid is working on the transformation of an educational laboratory on Mining Technology to develop an Innovative Lab in this field. As part of a project developed by several European partners and supported by EIT Raw Materials, this is one of the first experiences oriented to educate and train undergraduate and MSc students, by creating a space devoted to the development of their technical and entrepreneurial skills. Moreover, in these spaces, the use and integration of new tools and technologies will help to educate the future professionals who will develop their activity within the 4th industrial revolution, in which the mining industry is called to evolve giving place to “smart mining factories” with cyber-physical mining systems. This will be translated in a completely new way to interact among computers, automatic systems, robotics, and humans. This paper describes how this education project is being developed.

KEYWORDS

Innovative Labs, faculty development, creativity, learning experiences, program development, raw materials, Standards: 2, 3, 5, 7, 8, 9

INTRODUCTION

Innovation is at the heart of mining, but as technology continues to evolve at a rapid rate, mining companies need to look for new ways to leverage new tech to remain innovative and agile in a changing market. Like other industries, the mining sector is beginning to look at ways to leverage and learn from new entrants in this field, to become more competitive and cost-effective (Mining Global, 2018). To meet the challenges, the global mining industry is currently facing more competitive economic settings and increasing requirements and responsibilities for health, safety and environment (E. Clausen, J. Herrera Herbert, et al., 2017). The terms “Industry 4.0” (Marr, B. 2018), “Mining 4.0” (Bartnitzki, T. 2017) or “Mine of the Future” (Rio Tinto, 2008) are being widely discussed. The arising of technical priorities and objectives are critical in an energy-efficient, economically feasible and high-performance production of raw materials; increase in automation and autonomous systems for production, transportation, and processing while minimizing the impact on humans and the environment and maximizing the social license to operate (Marr, B. 2018) are aspects that need new generations of engineers.

Technological innovation is the key to future sustainability for the mining sector. However, technological developments based on the successful integration and implementation of sensor systems, modern information and communication systems as well as artificial intelligence, robotics, system automation, etc., will only lead to real breakthrough innovations if non-technical requirements related to social acceptance, environmental and social impact as well as regulatory constraints are additionally fulfilled. “Engineering shall no longer be the center of the society, but society shall become the center of engineering” (Kamp, A., 2017). The position of engineering in society is changing. Future mining engineers need to have a deep disciplinary knowledge while at the same time being strong in personal and interpersonal skills, leadership, innovation, entrepreneurship, and collaboration. Therefore, the mining engineer of the future needs to become an integrator of diverse skill sets and best practices together with being a coordinator of an increasingly interdisciplinary team.

The prime role of engineers is about innovation and designing systems (…), systems that actually design society as we know it (Kamp, A., 2017). Engineers focus on new ideas, on developing the best product. It is important that they have strong research, design and development skills. The main focus of the operational excellence role is process efficiency and finding ways to achieve the best total cost. These engineers oversee and standardize processes and have an eye for analyzing and solving problems. At last, the customer intimacy role has as a goal to provide customers with the best total solution and to respond to customers’ specific technological needs. Professionalism, communication, and ethical responsibility are important features for those engineers (Langie, G. & De Norre, J., 2016).

Education of the new generations of Mining Engineers has evolved the same way as has happened in other engineering disciplines. Developments introduced in other industrial engineering disciplines can be adapted and applied to mining disciplines. And at the same time, new actors have appeared to shift changes. One of these actors is EIT Raw Materials.

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 (EIT, 2018), 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 (EIT, 2018).

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.

Before 2017, in Europe, there were no academic institutes applying CDIO for primary resource related university programs (Exploration, Mining, Mineral Processing, and Metallurgy). Supported by the EIT Raw Materials through the Raw Materials Academy, the first international education projects are being developed to contribute to the implementation of the CDIO methodology in primary resources linked programs (Herrera Herbert, J. et al, 2017). Based on a previous preliminary project, a second new project started in 2018 focusing, among other objectives, in the development of innovative labs for education in mining engineering and related disciplines. This experience will be extended later to create similar facilities in education programs in the rest of the mineral raw materials value chain.

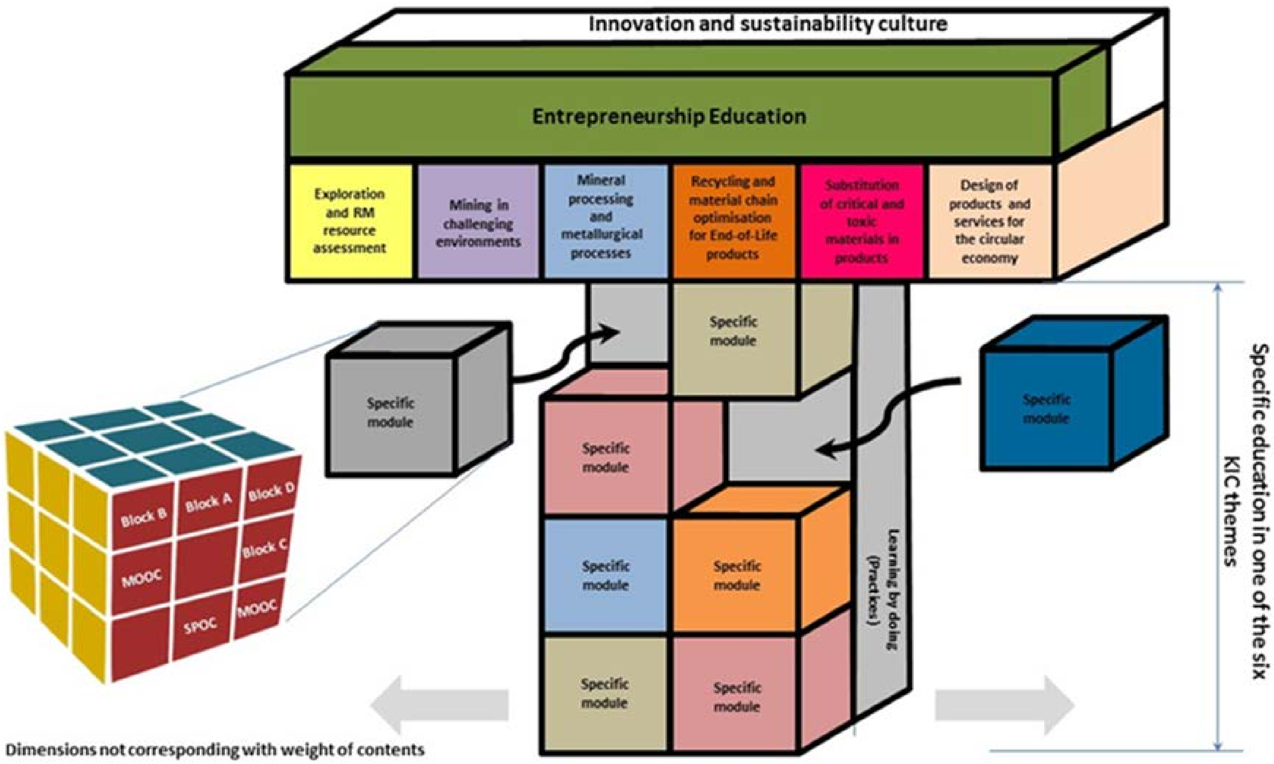

Figure 1. T-Shaped Professionals in Raw Materials (Herrera Herbert, J., 2017).

The majority of the existing innovative labs are facilities oriented for research activities and for 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.

This project started beginning in January 2018 and will finish ending December 2019. It is being developed by a consortium constituted by Chalmers University of Technology (Sweden), Universidad Politécnica de Madrid - UPM or Technical University of Madrid (Spain), Luleå University of Technology – LTU (Sweden), Clausthal University of Technology – CUT (Germany), University of Limerick – UL (Ireland), Luossavaara-Kiirunavaara Aktiebolag LKAB (Sweden) and RISE - Research Institutes of Sweden. This paper describes the preliminary results of the development of an innovative lab for undergraduate and MSc students in programs of the School of Mines of the Technical University of Madrid. It also describes how EIT Raw Materials is supporting this kind of initiatives.

EDUCATIONAL INNOVATIVE LAB DEVELOPMENT

Design is all about problem-solving and needs of an attitude of looking at the world around you and contributes to constantly changing and transforming it for the better. On the other hand, Innovation is finding and applying new approaches to address existing problems or serve unmet needs. Innovation is a new solution with the transformative ability to accelerate impact. Innovation can be fueled by science and technology, can entail improved ways of working with new and diverse partners, or can involve technologies, processes or application, new social and business models or policy, creative financing mechanisms, or path-breaking improvements in delivering essential services and products. Innovation has been and will be pivotal for reaching sustained, scalable solutions to the world's complex problems (Desai, A., 2019).

To be truly innovative, companies need to ensure a culture that supports new ideas and new ways of doing business efforts, but also execute those ideas. As mining companies become more ambitious with their capital investments, the difficulty for management teams is prioritising those technologies with the potential for the biggest impact. It's a question of experimenting, piloting, learning and adapting in 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 (McGrath, J. 2017). World leading mining companies have embarked on substantial training programs to upskill their workforce to enable them to handle a rapidly changing operating environment.

"To change the world, you have to be taught differently" (Kamp, A., 2017). The revolution that is enabled by *Industry 4.0* covers the spectrum from data science, data analytics, and cybersecurity, to next-generation robotics, advanced manufacturing technologies, smart materials, smart operations, the Internet of Things (IoT), predictive analytics, AR/VR technologies, etc., all of them applicable to any discipline in design, engineering or sciences. Engineers who are suitable for the emerging industrial revolution that is enabled by Industry 4.0, will need an imprint of (Kamp, A. 2017):

- Rigour of technical fundamentals of 21st-century engineering
- Deep skills in data science, data analytics, and cybersecurity
- Designing products and processes for the environment
- Life-cycle systems engineering knowledge
- Commercial awareness
- Protection of products and industrial frameworks
- Empathy for sustainability
- Ethical framework: powerful technologies will lead to unforeseen impactful consequences.

The CDIO Standard "Integrated learning experiences" champions the integration of disciplinary and practical knowledge along with personal and interpersonal skills. This both the most important and the most challenging of the CDIO Standards to implement: all of the experts are discipline-based, and each of them believes that their discipline is the most important thing in the universe. If you tell them they have to enrich that with creativity, ethical, systems thinking or other interdisciplinary skills, they find it extremely difficult because they themselves are not equipped for that (Skoltech, 2017).

CDIO is based on a commonly shared idea that engineering graduates should be able to: Conceive - Design - Implement - Operate complex value-added engineering systems in a modern team-based engineering environment to create systems and products (Malmqvist, J., 2016).

Conceive: includes customer needs, technology, enterprise strategy, regulations; and conceptual, technical and business plans
Design: includes plans, drawings, and algorithms that describe what will be implemented.
Implement: is all about the transformation of the design into the product, process, or system, including manufacturing, coding, testing, and validation.
Operate: refers to the implemented product or process delivering the intended value, including maintaining, evolving and retiring the system.

An education that stresses the fundamentals, covered in the context of Conceiving – Designing – Implementing - Operating systems and products include (CDIO, 2018) (I) a curriculum organized around mutually supporting courses, but with CDIO activities highly interwoven, (II) rich with student design-build-test projects, (III) integrating learning of professional skills such as teamwork and communication, (IV) featuring active and experiential learning, and (V) constantly improved through quality assurance process with higher aims than accreditation.

At this point, the Innovative Lab is an asset that will contribute to provide the training of the students who will become the next generation workforce that will integrate technologies, develop new ideas and execute those projects. The Innovative Lab can be the bridge from innovative thinking to execution, encouraging a culture of continuous improvement through empowerment of this future workforce.

The objective of an Innovative Lab in education is to: (I) train the students to be able to accelerate the adoption of emerging innovations; (II) create between the students a culture that's more conducive to innovation and informed risk-taking; and (III) contribute to enable the students to later be able to develop institutional capabilities to make innovation more strategic and systematic. But one of the main objectives is to show students that innovation labs developed by companies have the ultimate goal of creating new revenue streams or bolster existing ones by improving productivity or speed, and that means that there are many complex aspects to consider.

An innovation lab is a space physically located. They may receive many names ("innovation center", "creativity labs", "innovation space", "studios", "maker space", "innovation gateways", etc.), but generally, there isn't a difference. It's a new kind of physical environment that companies create, and generally, the mission is to serve as a focal point for innovation programs and activities. Other innovation initiatives may not be physically co-located, they can be as radical as Google's model of 20% 'free' time for workers to innovate, or simply involve setting up a group to collaborate with other industries, startups, or academia.

Innovative Labs have become a commonplace across industries from retail, to telecoms and travel; this includes mining companies, that have found a way to have effective innovation and re-innovation developments done in-house (Davies, B., 2016). 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 (Cruz, E. 2016). Innovation labs "recreate the atmosphere of a startup": they create an atmosphere in which risk-taking is encouraged, and everything is geared towards spurring creativity and nurturing new ideas, helping to develop technologies and business strategies, and recruiting tech talent (Innovation Enterprise, 2019). These spaces are places to develop creative efforts and experimental projects that do not necessarily aim to lead to commercial products but will certainly move the company forward through innovation. They allow cross-fertilization from other sectors, business models, and technologies, not to mention opportunities for cost saving and minimising the chance of making expensive mistakes.

Bringing the concept of Innovative Lab to the field of education and using it with undergraduate and MSc students, an Educational Innovative Lab is a place which provides facilities to nurture new ideas and help develop inquisitive perspective in youths of today. They engage students in innovative and creative activities and serve as springboards for new ideas and innovation by promoting student's creativity and helping them to recognize and train the skills they will need to face future challenges and meet rising aspirations. Specifically, embedding such creative pedagogies in science education through Innovation Labs would also have the potential to retain and promote talent.

The facilities used at an educational innovative lab should include:

- At least one interactive science/technology exhibits/experiments area to create excitement about science/technology through exploration and discovery of underlying principles. This will help promote logical thinking.

- A space to showcase innovative ideas/products/implements that have transformed our world or have made a significant impact on the way we conduct our lives along with respective inventors & innovators. This "innovation resources" area must show stories or inspirations behind such innovations/inventions should also be mentioned through appropriate modes. Besides these, implements/samples of appropriate technology and traditional knowledge systems, the possibility to find art and craft and other areas of importance may also be an element to take into account.

- An "Idea Lab" having the necessary basic facilities to pursue creative and innovative hobbies/activities that involve model making, basic science experimentation, design & fabrication of useful gadgets of practical use, teaching/learning kits or aids for better classroom transactions, testing of samples like soil, water, items, etc.
    - A "Break & Remake Corner": Students learn to do things with their own hands, dismantle, reassemble and remake devices/gadgets.
    - A "Build from scraps corner": Students learn more by doing things practically using day to day scrap.
    - An "Idea Box corner": Students generate their own innovative ideas and create an idea bank. The best ideas are chosen for experimentation/model making/project work.

- A "Design Studio": This area will offer a creative environment to design various objects products etc.

PRELIMINARY RESULTS

Although the project will finish in December 2019, some preliminary results in fostering creativity, introduction to the culture of innovation, learning by doing, and other aspects can be shown:

Fostering creativity

Innovative Labs may seem far from the objectives of a School of Engineering. Engineering is a technical subject and gaining a strong understanding of science and math is important, but creativity is also highly valued. Universities and companies are always looking for engineers who embrace their creative side as it helps them to think differently, which is perfect for designing new products or solving problems. The ability to visualise, dream up, draw and think outside the box are fantastic skills.

Problems exist for a reason and they're not simple to solve. Real life problems, don't have a unique and exact solution. That is why engineers have to be creative and use their knowledge, engineering tools, and expertise to solve the biggest problems. An educative innovation lab is an experimental place where students can experiment with the complexity of real problems. The work of an engineer isn't all about detailed measurements. All engineers design, create and innovate, essentially working as 'creative problem-solvers'. Engineers must go beyond the measurement and come up with new ideas and ways of solving problems every day. Design something also makes the work exciting and fun.

Introduction to the culture of innovation

The education innovative lab acts as a bridge between university students and project teams in companies, allowing a better approach to emerging innovations.

Real learning by doing environment

Students must apply their theoretical knowledge to resolve real cases. This will make them understand the importance of a solid background and, at the same time, develop the capacity to understand what new knowledge and skills are needed to resolve the situation and allow them to react to cover the gap.

At the same time, the work on real company needs allows them to train on the functions they will later perform once they leave the School of Engineering.

Innovative labs are not "showcase labs"

While innovative labs developed in companies usually have a small or medium size group of researchers and engineers, an educative innovative lab has to deal with medium to big size groups of students. Furthermore, students are training their skills and have no previous experience.

Another question is the difference between normal labs used in the different subjects that student study at the School of Engineering and the educative innovative lab. A facility of this kind is not a place where lecturer and professor make demonstrations for students but are a place where students can experiment, create and develop without any risk or knowing and understanding the risks. On the other side, and educative innovation lab is not a research lab for the use of Ph.D. students and researchers, as these facilities are equipped with tools and equipment that non-experimented students will use.

Educative innovation labs will not provide real innovation bust students will learn to innovate

This kind of labs must be designed to allow students to experiment and to learn to experiment. Students are there to learn to innovate, but no real innovations should be expected from these labs. The really successful innovation labs are the ones that are tied to a company strategic imperative and meet specific criteria, rather than just creating a cool space and holding meetings or training sessions in it. It's really critical that the innovation lab delivers added value to the corporate strategy, whatever that may be. In an educative innovative lab, the focus is on training as many people as possible, and the added value will come by developing professionals.

Innovative labs are not R&D labs

Discoveries in innovative labs are about ideas, not about discovering something specific. Educational innovative labs must then be about training student to develop their creativity and generate new ideas and concepts that may resolve a real problem. Furthermore, innovative labs are places where relationships and communication skills are fundamental for success, and these are some of the skill that must be trained in the educational innovative lab.

CONCLUSIONS

Engineers that are being educated today will constitute the workforce that will conceive, design, implement and operate the projects of the near future. They will have to work in environments that are in constant evolution. Technology and innovation will make imagination, ideas, and investment from governments and industry necessary to take advantage of opportunities. In other words, those new engineers will have to work differently. But working differently means learning differently, with new skills and wider knowledge in many aspects.

Many of the world's largest companies have developed some form of innovation lab as 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. The development of this kind of facilities for education in a university, just to be used as an education technique focusing on undergraduate and MSc students, is an innovative way to have the students getting close contact with real innovation and to develop creativity and engineering skills at the same time they get to understand the real dimension of the knowledge they are acquiring and how to apply it while resolving real problems.

Educational Innovative Labs haven't arrived to replace any conventional laboratory where students must learn the fundamentals of science and technology. Rather than that, these facilities must be focused to develop in the students a spirit to create a breakthrough, to encourage them to think on out-of-the-box solutions, to show them how to address problems creatively and contribute to develop an entrepreneurial mindset in them. Educational Innovative Labs are a complement to the whole program that the students are following, and where the real added value is to make them learn to be creative and how to develop and apply this creativity. But it is of critical importance that those labs are aligned with the study program and its outputs, to assure they can be at their most effective.

The Educational Innovative Labs can apply a wide range of methods and tools to stimulate creativity, guide discussions, moderate collaboration, stimulate group working as well as develop, prototype, and experiment solutions. Their self-proclaimed role is to "bring together the brains, methodology, and diverse tools for innovation. They encourage students to try things out on a small scale, take risks, prototype, test and accept failure as part of progress, re-inventing their own methods and approaches as they go along.

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