IMPLEMENTATION OF CDIO INITIATIVE IN NEW EUROPEAN EDUCATION PROGRAMS IN RAW MATERIALS

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Abstract

EIT Raw Materials, one of the six Knowledge and Innovation Communities (KICs) initiated by the EIT (European Institute of Innovation and Technology) and funded by the European Commission, has the mission to boost competitiveness, growth and attractiveness of the European raw materials sector via radical innovation and guided entrepreneurship. It aims to significantly enhance innovation in the raw materials sector by the sharing of knowledge, information and expertise. This must generate a significant impact on European competitiveness and employment by driving and fostering innovation and empowering students, entrepreneurs and education partners driving toward the circular economy.

To reach the vision, where the European Union’s industrial strength is based on a cost-efficient, secure, sustainable supply and use of raw materials, a new generation of skilled people entering industry, universities and research needs to be developed. Today’s technical MSc graduates in raw materials and especially primary resources (i.e. exploration, extraction, mining and mineral processing and metallurgy) meet the technical standards required by the raw materials industry across the full raw materials value chain and best suits large companies where they often act as specialists and experts. For small to medium enterprises as well as for our future engineers, other skills than technical are necessary.

EIT Raw Materials will educate people that will have an intra- and entrepreneurial mind-set 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.

The CDIO™ INITIATIVE is an innovative educational framework for producing the next generation of engineers. The framework provides students with an education stressing engineering fundamentals set in the context of Conceiving — Designing — Implementing — Operating (CDIO) real-world systems and products.

There are no academic institutes in Europe that have yet applied CDIO for primary resource related MSc programs. Within the KIC EIT Raw Materials Academy, the overarching brand of all the KIC’s education activities and created in order to stimulate education activities and foster new ways of learning and teaching, an approved education project is focusing on the implementation of the CDIO methodology in primary resources linked programs. The project started in 2016 and focuses on faculty and pilot case development and the contributing partners are from academia, industry and research institutes.

This project focuses on faculty development for an active and experimental learning by teaching the “technical” faculty through CDIO linked courses (entrepreneurship, business, etc.), communicative workshops, inspiration lectures and by involving the “business and entrepreneurial” faculty in exploration, mining, mineral processing and metallurgy related issues also through curriculum and pilot cases developed together with the industry.

This paper describes how this education project is being developed within the EIT Raw Materials and will give an overview of the needed skillset of future engineers demanded in the Raw Materials
primary sector. It presents key outputs about already developed and implemented activities in mining engineering and metallurgy related programs.

Keywords: Faculty development, international education project, EIT Raw Materials, MSc programs development, CDIO.

1 INTRODUCTION

The European Institute of Innovation & Technology (EIT) was created by the European Commission in 2008 and is dedicated to addressing the great challenge of creating ecosystems that foster favourable environments and frameworks for entrepreneurship-driven innovation within the existing EU innovation landscape. It has the vision of becoming the leading European initiative that empowers innovators and entrepreneurs to develop world-class solutions to societal challenges and creates growth and skilled jobs.

The EIT’s mission is to contribute to the competitiveness of Europe, its sustainable economic growth and job creation by promoting and strengthening synergies and cooperation among businesses, education institutions and research organisations. It should also create favourable environments for creative thoughts, to enable world-class innovation and entrepreneurship to thrive in Europe.

To fulfil the mission, the EIT has brought together six Knowledge and Innovation Communities (KICs) until 2017. One of these KICs, launched in 2014 and has a focus on the raw materials value chain (exploration, extraction, mineral processing, recycling and material substitution). This KIC is named EIT Raw Materials and is supported by more than 115 partners from industry, research and universities. The EIT Raw Materials, the strongest consortium ever created in the world in the raw materials field, has the ambitious vision of turning the challenge of raw materials dependence into a strategic strength for Europe. Its mission is to boost the competitiveness, growth and attractiveness of the European raw materials sector via radical innovation and entrepreneurship paying particular attention to systemic thinking and de-siloing across the value chain. This KIC will integrate multiple disciplines, diversity and complementarity along the three sides of the knowledge triangle (business, education and research) and across the whole raw materials value chain [4].

All learning and education activities in the EIT Raw Materials are under the umbrella of the Raw Materials Academy, which is the overarching brand of all the education activities of the KIC. The Academy was created in order to stimulate education and lifelong learning activities and foster new ways of learning and teaching with special focus on the strengthening of innovation and entrepreneurship in the whole raw material chain. Activities across the entire ecosystem of learners (PhD students, Masters’ students, industrial partners, professionals within the raw materials sector, and wider society) foster new ways of learning and teaching by linking academia, industry and research organisations.

EIT Raw Materials will educate people that will have an intra- and entrepreneurial mind-set 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.

The CDIO™ INITIATIVE is an innovative educational framework for producing the next generation of engineers. CDIO is based on a commonly shared premise 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.

There are no academic institutes in Europe that have yet applied CDIO for primary resource related MSc programs. Within the EIT Raw Materials Academy, and following the principle of developing new ways of learning and teaching, an approved education project is focusing on the implementation of the CDIO methodology in primary resources linked programs. The project started in 2016 and focuses on faculty and pilot case development and the contributing partners are from academia, industry and research institutes.

This project leads to faculty development for an active and experimental learning by teaching the “technical” faculty through CDIO linked courses (entrepreneurship, business, etc.), communicative workshops, inspiration lectures and by involving the “business and entrepreneurial” faculty in exploration, mining, mineral processing and metallurgy related issues also through curriculum and pilot cases developed together with the industry.
2 METHODOLOGY

The function of the engineering profession is to manipulate materials, energy, and information, thereby creating benefit for humankind. To do this successfully, engineers must have a knowledge of nature that goes beyond mere theory—knowledge that is traditionally gained in educational laboratories [7]. In the case of an Engineering profile in the Raw Materials primary sector (exploration, extraction, mineral processing and metallurgy), this is a really versatile career and after graduating students find that there are plenty of different areas in which they can specialize. But on top of this, safe, effective and responsible mineral production relies on intelligent, skillful practitioners who can operate highly sophisticated mining devices. The primary roles of these professionals include knowing key aspects of the professional development of an exploration geologist, a mining engineer and a mineral processing engineer. This means knowing how the prospection and exploration processes are taken ahead, knowing about evaluating, planning and directing the construction process of a mine, how companies extracts minerals and resources from the earth in the most safe, economic and environmentally sound manner, how the mineral processing is performed, how minerals are commercialized. They may also sample mineral deposits in collaboration with geologists, prepare the layout of the mine development with a mining engineer, conduct research aimed at improving the efficiency and safety in mines, or even plan and coordinate the employment of mining staff and equipment. These new professionals in the Raw Materials sector can work in the field, corporate head offices of mining companies, government departments, or even universities and research centres.

From the Raw Materials Academy point of view, this means educating ‘T-shaped’ professionals, who are ready to provide their hands-on expertise to industry and research. This will lead to the formation of “T-shaped” professionals that are broad and holistic and have a deep understanding of specific aspects of the value chain and a good understanding of the Raw Materials value chain and a mindset for innovation, entrepreneurship and sustainability.

The T-shaped professional will combine an in depth knowledge of his own discipline with a sound understanding of the challenges appearing along the whole raw materials value chain, such as exploration, extraction and processing of primary resources, recycling of secondary resources and substitution of critical and toxic materials. It is essential that these T-shaped professionals understand their role within the value chain as actors of a more circular economy.
The education of a “T-shaped” student with an understanding of the full raw materials value chain and with a mind-set for innovation, and entrepreneurship focusing on sustainability needs a different focus to the one existing in most of the European universities.

Since the publication of “Rethinking Engineering Education: The CDIO Approach”, the number of universities that have adopted a CDIO approach in at least one of their engineering programs and joined the collaboration of the CDIO initiative has increased fourfold. While the approach retains the same basic principles, its application is now found in a much broader range of engineering disciplines, for example, chemical engineering, biological engineering and mining engineering. Moreover, the general framework of the approach is now being applied in programs in business management and other professional programs [1].

There are no academic institutes in Europe that have yet applied CDIO for raw materials related MSc programs [2]. When EIT Raw Materials announced their calls for Learning and Education Programs in 2015 the project described in this communication was submitted by a consortium formed by the following partners or the EIT Raw Materials: Luleå University of Technology (Sweden), Chalmers University of Technology (Sweden), Technical University of Clausthal (Germany), Universidad Politécnica de Madrid (Spain), University of Limerick (Ireland), Luossavaara-Kirunavaara AB – LKAB (Sweden), RUSAL Aughinish Alumina (Ireland), Delft University of Technology (Netherlands) and SP Sveriges Tekniska Forskningsinstitut AB (Sweden).

The project’s objective is the implementation of CDIO (Conceive Design Implement and Operate) in typical technical MSc programs. Implementing CDIO would result in a higher number of T-shaped students at existing running MSc programs and a faculty with increased pedagogic and teaching engineering skills. The implementation of CDIO was to be based on a continuous industry and research involvement through discussion of programs contents and through pilot and real cases. Also the students will be better prepared for the engineering working skills and by that have an insight in the whole raw material chain, compared to today’s technical graduates [3].

The project focuses on faculty development on a first stage and in active and experimental learning and design of student workspaces and labs on a second stage. By teaching the faculty through CDIO linked courses (entrepreneurship, business etc.), communicative workshops, inspiration guest lectures and through better developed curriculum with more clear learning outcomes and also by building up or
improve student experimental labs in Raw Materials, all partners in the knowledge triangle will benefit of an CDIO implementation.

During the first year of this project the faculty development as well as developing CDIO pilot cases for EIT RM will be in focus. In the coming years of the project, the design and build up of experimental RM labs will be the scope. To successfully implement CDIO the university itself, programme responsible and the teaching faculty need to be committed [2]. But this is also fundamental as EIT-labelled educational programs at Master and PhD levels foster students to become more creative, innovative and entrepreneurs. EIT-labelled programs ensure that students demonstrate skills and competences in all the following areas: Innovation, Entrepreneurship, Leadership, Creativity and Research.

Once there is a group of committed staff, the mobility and collaboration between universities and exchange of past experience is likely to drive the CDIO implementation. By EIT Raw Materials funding the partners in the project have the great opportunity to get the university committed and faculty involved to discuss and cooperate during the implementation of CDIO.

2.1 Faculty development (WP-1)

Under the coordination of the Luleå University of Technology - LTU (Sweden), WP1 is been focused on faculty development (CDIO Standard 9 and 10) with inspiration lectures developed at the Universidad Politécnica de Madrid (Spain) and at the Technical University of Clausthal (Germany), and faculty courses developed and given by the Chalmers University of Technology (Sweden) and the University of Limerick (Ireland) during 2016. These courses will be followed by the ones to be given at the Delft University of Technology (Netherlands) in May 2017 and at the Luleå University of Technology (Sweden) in October 2017.

The aim of WP1 is to create a faculty course both containing the CDIO approach as well as examples and cases from the raw material sector. Hence in the final faculty course in October 2017, the programmes and courses that have been developed in WP2 will be presented.

The universities offering programmes and courses in the RM sector are, as part of EIT Raw Materials, expected to include innovation, entrepreneurship and business skills, in their MSc programmes. On the other side, business and entrepreneurial schools exist at most universities, but these often deliver a "standard package" of project and courses that are not specific for the Raw Materials sector.

The win-win situation of this work package is that the “technical engineering” faculty will be taught through CDIO linked courses on business and entrepreneurial skills and that the “entrepreneurial” faculty will be taught exploration, mining, mineral processing and metallurgy related issues. The final issue is to create and make possible a transfer of “standard packages” from business and entrepreneurial schools to a content that is specific for the Raw Materials sector and warranted by the EIT Raw Materials Academy.

Inspirational lectures linked to CDIO as mentioned above have been included in WP1 in order to get the work started and faculty within the area of exploration, mining, metallurgy and mineral processing interested in the subject [3]. The first inspirational lecture was given in Madrid in May 2016 and the second in the end of September 2016 in Clausthal. After each inspiration lecture, the project coordinator at LTU briefed the audience on how this can be implemented in our raw material programmes. The major inspirations from the lectures and the inputs that the partners thought they should use in their continued work was to focus on the student contribution instead of the teacher contribution and to use a variation in assessment methods instead of only written exams in the whole program [2].

Complementary activities to this WP-1 but also important in order to profit of created synergies were the participation at the EIT Raw Materials Academy workshops on Entrepreneurial Education at Uppsala University in March 2016 and the workshop on Lifelong Education hold in Berlin in October 2016. Special importance was to be given to the participation at the EIT Labelling cross-KIC workshop hold in Paris in April 2016.

2.2 Development of CDIO Pilot cases within EIT Raw Materials (WP-2)

As the vision is that the university partners include entrepreneurship and innovation in their typical technical engineering programmes, it is important to begin with creating a few EIT RM CDIO pilot cases. But as the regulation in each country regarding the quality in education is different in many
aspects and each university has its own criteria regarding the programs development, the situation and possibilities for CDIO implementation for each partner is unique and slightly different from the others.

MSc programmes with focus on primary resources and mineral exploration, mining engineering and mineral processing are given at Universidad Politécnica de Madrid (Spain), Luleå University of Technology (Sweden) and Technical University of Clausthal (Germany). The pilot case development in WP2 will be both on programme and course level.

The first case will focus on mining and be developed at Luleå University of Technology - LTU (Sweden) during 2016 by personal support and coaching by CDIO experts as well as great involvement by LKAB.

The focus at Universidad Politécnica de Madrid (UPM) has been on course development at the School of Mines, with the collaboration of professors of the School of Industrial Engineering as advisors. For the course development at UPM, the participation of an external institution for student practices on machinery has also been scheduled.

The focus at Technical University of Clausthal has been and is on course development within the international MSc Mining Engineering. The main focus has been on courses in mine ventilation, the integration of sustainability aspects in Mining Engineering Education.

Courses within primary resources are also given at Chalmers University of Technology, University of Limerick and at Delft University of Technology and are under development work.

In the spring 2017, the pilot case will be presented to all partners in the project at a workshop in Sweden coordinated by Luleå University of Technology and after its presentation, the pilot case will be evaluated by all partners. Based on the result from the evaluation new pilot cases will start to develop during 2017 with focus on exploration and, mineral processing (both at LTU) and on mining on both Technical University of Clausthal and Universidad Politécnica de Madrid [3].

In autumn 2018, the pilot cases will be presented to all partners in the CDIO project at a workshop to be held at Luleå University of Technology. During autumn 2018 (Edelbro et al, 2015) the project will also be evaluated. Based on the result from the evaluation, new pilot cases will be suggested for 2018-2019 with focus on metallurgy and exploration at Luleå University of Technology and on exploration geology on both Technical University of Clausthal and Universidad Politécnica de Madrid.

2.3 Development of Experimental Raw Material labs for students (WP-3)

In entrepreneurial schools it is obvious to have a lab for students to foster creativity and innovativeness. In the classical Engineering education, labs are fundamental to prepare students to practice engineering and, in particular, to deal with the forces and materials of nature. Thus, from the earliest days of engineering education, instructional laboratories have been an essential part of undergraduate and, in some cases, graduate programs. Indeed, prior to the emphasis on engineering science, it could be said that most engineering instruction took place in the laboratory [7].

Most science-based courses include practical experimental activity in the laboratory. Many academics and authoritative bodies would claim that a significant level of such activity is essential to the formation of technologists. The emphasis on laboratories has varied over the years. While much attention has been paid to curriculum and teaching methods, relatively little has been written about laboratory instruction, and while there seems to be general agreement that laboratories are necessary, little has been said about what they are expected to accomplish.

It is useful to distinguish among three basic types of engineering laboratories: development, research, and educational. While they have many characteristics in common, there are some fundamental differences. These differences must be understood if there is to be agreement on the educational objectives that the instructional laboratory is expected to meet.

Engineering students go to the labs in a completely different way than practicing engineers. When students, especially undergraduates, go to the laboratory, it is not generally to extract some data necessary for a design, to evaluate a new device, or to discover a new addition to our knowledge of the world. Each of these functions involves determining something that no one else knows or at least that is not generally available. Students go to an instructional laboratory to learn something that practicing engineers are assumed to already know. That “something” needs to be better defined.
through carefully designed learning objectives if the considerable effort devoted to laboratories is to produce a concomitant benefit. [7].

Laboratory instruction has been complicated by the introduction of two phenomena in the past three decades: the digital systems, the development of on-line learning, the possibilities of the Internet and the introduction of virtual reality and augmented reality in education.

These systems have opened new possibilities in the laboratory, including simulation, automated data acquisition, remote control of instruments, and rapid data analysis and presentation. The reality of offering undergraduate engineering education via on-line learning has caused educators to consider and discuss just what the fundamental objectives of instructional laboratories are. These discussions have led to new understandings of laboratories and have created new challenges for engineering educators as they design the education system for the next generation of engineers.

The discussions inside the CDIO project have taken in consideration labs for raw material students as well as how to engage SMEs and start-ups in the developing programs. To add the possibility for networking and see how others are working with CDIO, programs and courses, the participation at international CDIO conferences has also been included as an important task of the project.

This WP will start ending 2017 and will include the design and development of student workspaces and experimental lab. This WP will require increased contact between all partners as well as inspiration from other areas such as science centers, schools etc.

3 PRELIMINARY RESULTS

As this communication is over a running project, results can only be considered as preliminary. The introduction of new methodologies and a whole raw materials value chain perspective is helping to understand how the existing programs should be adapted for the requirements of a much more intelligent raw materials industry. Having the program development work validated by stakeholders will undoubtedly reduce the gap between learning and education institutions and the needs of modern industry. Since this project has partners within the whole knowledge triangle (industry, research and academia) the programs have the possibility to include more real and complex problems. Therefore, it is positive that students and teachers can act as ambassadors of the programmes and with new ambassadors trained every year.

Up to date, four different events for the faculty, with in total more than 110 registrants, have already been created in the project. The events took place at different countries and locations which made it possible for many partners to attend. Two more courses will take place during 2017 widening the geographical dissemination and attracting a relatively important number of participants among the staff of the participant universities and more activities for 2018 are envisaged. The faculties at the universities are now a part of a large pedagogic network through CDIO as well as a large network within the discipline.

Regarding the pilot case development, 11 stakeholders from the industry were involved as well as faculty at the different universities. Hence more than 30 people were directly involved in programme and course development.

Through WP1 and WP2 new teaching methods and pedagogic tools have started to be used in the raw material MSc programmes. All the innovations in terms of teaching that the project is working on include aspects defined under the vision of the EIT Raw Materials Academy:

- The promotion of problem-based learning, self-organisation and learning by doing.
- The offer of an open learning environment complemented, in the future, with a series of online courses.
- Enabling a high degree of mobility of students and professionals.
- Facilitating access to experimental platforms and pilot plants for hands-on training
- Adopting a strong multidisciplinary approach (e.g. joint courses across sectors)
- Thinking beyond boundaries and systematically exploring and generating new ideas
- Transforming innovations into feasible business solutions
- Joint curriculum development
As a result we will see modified courses and programmes and new developed curriculum with clearer learning outcomes. In total the implementation of CDIO will influence and inspire more than 150 students within primary resources programmes and it will also involve more than 50 faculty members.

4 CONCLUSIONS

The Learning & Education activities are one of the three crucial components of the knowledge triangle. All learning and education activities developed under the umbrella of the EIT Raw Materials Academy aim to educate “T-shaped” professionals with an understanding of the full raw materials value chain and a mindset for innovation and entrepreneurship focusing on sustainability that are enables to create and develop new “game changing” businesses. Wherever possible, education activities include hands-on experience utilising real infrastructure and encourage mobility between industry, research and academia for everyone across the KIC ecosystem of learners. Innovation in education is also a key ingredient, helping to boost and enable business emerging from educational activities [6].

The T-shaped professional will have a strong entrepreneurial mind-set and combine an in depth knowledge of his own discipline with a sound understanding of the challenges appearing along the whole raw materials value chain, such as exploration, extraction and processing of primary resources, recycling of secondary resources and substitution of critical and toxic materials. It is essential that these T-shaped professionals understand their role within the value chain as actors of a more circular economy.

The CDIO standards are particularly interesting for the development of new programs in Raw Materials, particularly in primary resources, where there is no previous experience in Europe. With the objective of creating an education program for Engineering students where at the end of the courses the student is able to conceive, design and implement, at a functional prototype level, an engineering project of moderate complexity it is of a vital importance to pay also attention to the education of the staff. The challenge of finding teachers motivated for offering this type of course is important to be analysed in order to reduce as much as possible any posterior demotivation of some of them. In this project, this has been a starting point.

With the CDIO methodology, students will also be capable of communicating the data acquisition process, theory involved, construction and performance of the team project, through oral and written presentations; nevertheless rubrics for communication skill should be applied consistently in every section and continuously evaluated in posterior courses. Entrepreneurial and business skills, as well as social dimension are aspects to be fully taken into account in the design of these new programs.

The new educational programs and activities organized under the umbrella of the EIT Raw Materials Academy and based on the standards and criteria of the CDIO initiative, will benefit from this dual nature making sure to involve all stakeholders of the raw materials value chain and to contribute to the creation of new opportunities in the raw materials sector and the related supply and availability challenges. The efforts developed in this learning and education project are aligned with the general objective of achieving a “paradigm shift” in Raw Materials education by introducing entrepreneurship, supporting the effective transformation of ideas into businesses.

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