CDIO COURSE DEVELOPMENT FOR FACULTY IN RAW MATERIALS PROGRAMMES

Kanishk Bhadani, Erik Hulthén, Johan Malmqvist

Chalmers University of Technology, Sweden

Catrin Edelbro

Luleå University of Technology, Sweden

Alan Ryan, David Tanner, Lisa O'Donoghue

University of Limerick, Ireland

Kristina Edström

KTH Royal Institute of Technology, Sweden

ABSTRACT

In Europe, the existing MSc programmes which are linked to the thematic Raw Material content often focus mainly on technical knowledge in itself, and students graduate as professionals who know how to solve pre-defined technical problems. Students in such programmes seldom practice entrepreneurial, communication and innovation skills at a level that is needed in working life. On the other hand, the CDIO Initiative has developed a framework for modernizing engineering education by introducing such skills and thinking into the technical programmes and courses. It is widely discussed in the CDIO community that one of the constraints in implementing CDIO is faculty staff professional development. CDIO standards 9 and 10 focus on the faculty development and competencies both in terms of pedagogic as well as learning methods to deal with personal and interpersonal skills, and product, process, and system building skills. In order to bring a change and implement CDIO into the Raw Materials programmes in Europe, a modular course for training in CDIO was developed and delivered for the faculty member in the Raw Materials sector. This paper accounts for the development of the faculty training course, and provides a unique perspective on the implementation of CDIO into raw materials related programmes capturing the different models of implementation from different universities' programmes and courses. The various universities involved provide programmes and courses across the entire value chain of raw materials from mining and minerals processing to materials design, sustainability and recycling. This paper will serve as a reference for the educators to develop and implement CDIO education methods in specific disciplines as illustrated here in the field of raw materials related programmes.

KEYWORDS

CDIO Standards 9, 10; Faculty Development; Raw Materials; Course Development

INTRODUCTION

Modern engineers are engaged in all phases of the lifecycle of products, processes and systems who serve the need of the society. It is the responsibility of the engineering education to support their preparation for this. In Europe, the existing MSc programmes which are linked to the thematic Raw Materials (RM) content are often much focused on technical knowledge in itself, and students graduate as professionals who know how to solve pre-defined technical problems. Students in such programmes seldom practice entrepreneurial, communication and innovation skills at a level that is expected and needed in working life.

Today's MSc graduates best suit large organisations where they are often destined for roles as technical specialists and experts. The large company can allow time for newly graduated engineers to learn on the job with senior colleagues, sometimes through trainee programs, etc. Neither small and medium-sized enterprises (SMEs) nor consultancies can seldom offer the same conditions for a slow start, and therefore the graduates need some additional skills in order to be more productive and independent from the start. Business and entrepreneurial schools exist at most universities, but these often gives a "standard offer" and seldom a tailor made content that is specific for Raw Materials sector.

The CDIO Initiative focuses on modernizing engineering education by introducing such skills and thinking into the technical programmes and courses. By implementing CDIO, students will encounter more real-world problems which are cross disciplinary and are set in a context which may include societal, legal, environmental and business aspects. Such problems are often characterized as complex and ill-defined, and there can be one or many solutions to evaluate in the light of the specific conditions. Members in the CDIO Initiative have the opportunity to continuously develop as CDIO collaborators and regularly develop materials and approaches to share with others (Crawley et al., 2014).

The project CDIO (Edelbro *et al.,* 2017) within EIT Raw Materials (Knowledge and Innovation Community - KIC) focuses on faculty development, active and experimental learning, and in future proposals most likely on design of student workspaces and laboratories. The project is aimed at bringing the change and contributing the higher education jobs and growth through enhancing the link between the knowledge triangle, i.e. the effective links between education and research to innovation (Allinson *et al.*, 2012). This is associated with closer cooperation between education institutions, research organisations and businesses (Ranga & Etzkowitz, 2013). As a contribution to the development of the RM sector, the aim here is to strengthen engineering faculty competences related to innovation, entrepreneurship, business, etc. This objective is addressed by organising CDIO linked courses, communicative workshops, and inspirational guest lectures; by involving the "business and entrepreneurial" faculty in exploration, mining, mineral processing and metallurgy related issues; and also through curriculum and pilot cases developed together with industrial partners in the knowledge triangle.

Within this project there are several end customers and key beneficiaries such as RM industry, large traditional companies, entrepreneurs and SMEs, society, research institutes, students and universities. Students in the MSc programmes will develop entrepreneurial, innovative, communicative and collaborative skills, as well as other professionally relevant competencies, within the technical area of RM. During the first year of this project, the faculty development as well as developing CDIO pilot cases for EIT RM is in focus. Engineering faculty members at the universities have the opportunity to increase their understanding of the professionally relevant competences that the students need to develop (CDIO Standard 9), as well as their own competence in matters related to designing programmes and courses to address these skills (CDIO Standard 10). Further, the university faculty get the possibility to communicate and learn from others through EIT partners, and throughout the large community of CDIO members.

This paper describes the development of, and the content for, a faculty training course used to introduce CDIO into raw materials related programmes and courses. The two-day CDIO course has been given on two occasions in the academic year 2016-2017, held at two locations: Chalmers University of Technology, Sweden, and University of Limerick, Ireland. The universities involved provide programmes and courses across the entire value chain of raw materials – from mining and minerals processing to materials design, sustainability and recycling. Implementation of CDIO into this wide range of programmes and courses will therefore provide a unique perspective.

LITERATURE REVIEW

The following section highlights the previous work and approaches which has been used to develop faculty training activities for CDIO and project-based learning (PBL).

The CDIO Initiative started in the year 2000 with the aim to reform engineering education for better professional preparation. The vision of CDIO is to educate students to master a deeper working understanding of technical fundamentals, the ability to lead in the creation & operation of products and systems, and an understanding of the role and strategic value of research (Berggren *et al*., 2003; Crawley, *et al.*, 2014). Over the past 16 years, the initiative has grown from the four original founders (MIT, Chalmers, KTH and Linköping University) to a community of over 130 institutions. The framework for engineering education development has been progressed and extended through input from this dynamic community including most engineering disciplines. Within the initiative, discussions cover a range of topics related to the improvement of engineering programmes. This includes issues related to teaching product, process and system development, entrepreneurship, leadership, and emphasising personal, professional and interpersonal skills. The updated versions of the CDIO syllabus (Crawley *et al.*, 2011) and CDIO Standards encapsulate the scope, rationale and generalised goals for developing programme and courses (see "CDIO Syllabus 2.0 | Worldwide CDIO Initiative", 2017; "CDIO Standard 2.1 | Worldwide CDIO Initiative", 2017).

Despite the fact that Standards 9 and 10 identify faculty competence as a key issue in engineering education development, there is a comparatively small number of articles in the CDIO literature concerning course development and deployment for training of faculty. Chuchalin *et al.* (2015) presented a modular course design for the development of CDIO Academy in Russia and argues that commitment of university, programme designer and teaching staffs plays an important role for successful implementation of CDIO. Experience has shown that peer learning, exchange of past experience, and collaboration between universities are some of the major driving factors to successfully implement CDIO (Loyer *et al.*, 2011; Chuchalin *et al.*, 2015; McCartan *et al*., 2016). Kozanitis *et al*. (2009) found similarities in the CDIO teaching methods between five universities and five different subject and course structures, especially, they give examples on how CDIO is taught to their faculty. At KTH Royal Institute of Technology (KTH), Stockholm, Sweden, CDIO was the underpinning for a faculty development course taken since 2004 by a total of 700 faculty members. One of the requirements in this course was that participants should present a redesign of their own course, along with a reflective document providing the rationale for their educational choices. From Singapore Polytechnic, they give an example of a roadmap where the subject knowledge is divided into discipline knowledge and the 13 CDIO skills ("CDIO Syllabus 2.0 | Worldwide CDIO Initiative", 2017).

Although Edström & Kolmos (2014) have shown that CDIO and PBL (i.e. problem and project based learning) are quite different in scope, there is much to be learnt from examples of faculty training for PBL. Farmer (2004), shows that early faculty training and involvement is crucial for transition of curriculum change to adopt project based learning. The research, within a medical and health science education setting, showed that basic workshops on tutoring and developing PBL with mentoring from experts helped in competence development for the teaching staffs (Farmer, 2004). A similar mentoring approach for training faculty was shown to have a positive impact on faculty development (Smith & Ingersoll, 2004). Loyer & Maureira (2014) describe thoroughly, through proposing a model, how a course is transferred from one teacher to another with a mentoring approach, which also resulted in changes in the course to allow students to be more active. Malmqvist *et al.* (2008) highlight the need for, but also the lack of, organized forward looking competence programmes at a few universities. They point out several areas where there is a need for faculty development in modern universities. Some of the competences identified are particularly relevant to apply in engineering courses in the raw materials sector, e.g. using project based teaching methods, and contributing to the universities strategic goals.

From literature, it can be seen that the CDIO is a community-driven initiative and learning from shared experience and mentoring are important aspects. In the raw material sector, the university education today is overall traditional compared to other fields such as mechanical engineering and the examples of CDIO implementation in RM related programmes/courses are scares. This paper describes the important segment of making the RM sector's education modern. In this paper, the development of the CDIO course is described including the formulation of learning objectives, the design of a course framework aligned with these learning objectives, development of course content relevant for implementing CDIO in raw materials programmes, and finally feedback from the participants. This is followed by the discussion on the relevance of such CDIO courses into raw materials and future work to be carried forward.

CDIO FACULTY DEVELOMENT COURSE LEARNING OBJECTIVE

The implementation started with an initial meeting with all stakeholders, including the participating university representatives and company representatives. Guided by the EIT RM project scope and feedback from CDIO experts, the foundation was laid through the development of the learning objective for the course, see Table 1. The learning objectives basically covered three aspects; the rationale for using CDIO (L1), the application of CDIO in curriculum development (L2) and the application of CDIO in course development (L3).

CDIO FACULTY DEVELOPMENT COURSE FRAMEWORK

The implementation of CDIO in curriculum and course design requires supporting the faculty members to understand the concepts and methodologies of CDIO. Taking a cue from different faculty training activities carried out across the CDIO community, the CDIO faculty development course was organised in a modular framework. Using the learning objectives as a basis for course design, the CDIO faculty development course was organised in 3 modules as shown in Table 2. Each module is mapped to the learning objectives and the content is further mapped to the modules. The course is typically delivered using seminar presentations, case study presentations, workshops, active discussions, and laboratory & workspace tours.

Table 1: List of Learning Objectives for CDIO Faculty Development Course

L1	Explain the rationale of the CDIO approach to engineering education.
L2	Apply the CDIO methodology to curriculum development, including
a.	Formulating learning outcomes on the program level
b.	Devising a curriculum to integrate disciplinary fundamentals with personal and professional skills and attitudes, in particular business and entrepreneurship skills
c.	Giving examples of strategies to enable and drive program-driven course development
L3	Apply the CDIO methodology to course development, including
a.	Formulating learning outcomes on the course level
b.	Developing appropriate learning activities for discipline-led learning and for problem based/project organized learning
c.	Developing appropriate assessment methods aligned with the intended learning outcomes
d.	Suggesting ways to address business and entrepreneurship skills on the course level

Table 2: Modular Design of the CDIO Faculty Development Course and Learning Objective Alignment

Module 1 (M1)	Train and create awareness of CDIO initiative and how to implement CDIO in raw material related programme and course development.	
a.	CDIO Introduction, History	L1
b.	CDIO Syllabus and Standards	L1
c.	Methods for curriculum design	L2 - a, b
d.	Methods for course design	L3 - a, b, c
Module 2 (M2)	Show examples and case studies to give ideas and inspiration to the practitioner to implement CDIO both at programme level and course level.	
a.	Case study on curriculum design	L2 - c
b.	Case study on course design	L3 - a, b, c
c.	Case study on involvement of Business and Entrepreneurship in Engineering	L3 - d
Module 3 (M3)	Developing CDIO based curriculum, courses and projects for the specific programmes and courses related to the field of raw materials including mining and metallurgy aspects with industrial involvement.	
a.	Workshop on curriculum design	L2 - a, b, c
b.	Workshop on course design	L3 – a, b, c, d

CDIO FACULTY DEVELOPMENT COURSE CONTENT AND IMPLEMENTATION

The modular design of the course provides flexibility for the customization of the course content for practical reasons. There are many practical challenges in building and organising such courses for universities, for instance, the location of the course delivery since some participants need to travel, availability of experienced facilitators, scheduling and duration of the course, and motivation from participants for attending the course. The pilot CDIO faculty development course was hosted at two locations. The content of each course was customised, as described in the following sections.

CDIO Faculty Development Course, Chalmers

The first two-day CDIO Faculty Development course was organised at Chalmers University of Technology on 25th - 26th October, 2016. A summary of the course content is presented in Table 3. Sessions on the topics were facilitated by experienced faculty members, programme

Table 3: Course Content for CDIO Faculty Development Course, Chalmers

Day 1	**Topic**	**Module**	**University**	**Delivery Type**
	Introduction to CDIO	M1: a, b	Chalmers	Seminar
	Program Development	M1: c	Chalmers	Seminar
	Course Development	M1: b, d	KTH	Seminar
	Industrial Engagement on Teaching	M2: a	Limerick	Seminar
	CDIO Case Study - Program Development	M2: a	Chalmers	Case Study, Active Discussion
Day 2	CDIO Tools for Teaching Material - Case Study on Product Development Course	M2: b	Chalmers	Case Study, Active Discussion
	CDIO - Case Study on Course Development	M2: b	Limerick	Case Study
	Design Build - Simulation Based Learning	M2: b	Chalmers	Case Study, Laboratory & workspace tour
	CDIO- Business and Entrepreneurship	M2: c	Limerick	Case Study

developers and CDIO experts from three universities: Chalmers University of Technology, Sweden; KTH Royal Institute of Technology, Sweden; and University of Limerick, Ireland. The case studies presented were from mechanical engineering programmes, business and entrepreneurship programme, computer science and IT programmes and a naval architecture programme.

Participants and their Feedback

In total, 31 participants from 9 universities participated in the course and feedbacks was collected through a survey after the course. Overall, the participants were highly satisfied with the course, rating it 5.13 on a scale from 1 to 6 (15 responses). The participants found the CDIO examples and experiences to be valuable for learning about CDIO. Other notable positive highlights from the course experience were: the diversity in examples of project-based learning (design-implement experiences), the cross disciplinary audience, and discussions stemming from the presentation of case studies. Feedback also demonstrated a need to reduce the time for presentation, and include more of workshop/hands-on experiences and group activities. The main learning outcomes, or take away messages for the participants were the structured and systematic methods to change programmes and courses; and new strategies to implement the same. They also appreciated that the course gave the rationale behind CDIO implementation, while real cases and scenarios gave ideas and inspiration to change their own programmes and courses.

CDIO Faulty Development Course, Limerick

The second two-day CDIO Faculty Development course was organised at University of Limerick, Ireland on 10th - 11th January, 2017. Similar to the first event, topics were delivered by CDIO leaders from Chalmers University of Technology, Sweden; KTH Royal Institute of Technology, Sweden; and University of Limerick, Ireland. Having examined the feedback, detailed in the previous section, the Faculty Development Course in UL focused on delivering “more hands on experience and group activities”, while ensuring that participants were still grounded and aware of the CDIO fundamental principles and standards. The course content summary is presented in Table 4.

Table 4: Course Content for CDIO Faculty Development Course, Limerick

Day 1	**Topic**	**Module**	**University**	**Delivery Type**
	Introduction to CDIO	M1:a, b	Chalmers	Seminar
	Program Development	M1:c	Chalmers	Seminar
	Course Development	M1:b, d	KTH	Seminar
	Instructional Method and Student Learning	M2:a, b	Limerick	Seminar
	CDIO Self-Assessment Standards & Rubric	M1:b	Chalmers	Active Discussion/Round table
	Methods to Improve Student Learning	M2:a, b	KTH	Active Discussion
Day 2	CDIO Tools – Put learning back into Project Based Learning	M2:a, b	KTH	Case Study, Active Discussion
	Enabling and Facilitating Entrepreneurial skills	M2:c	Limerick	Seminar
	Design Build Compete	M2:b	Chalmers	Active Discussion

Participants and their Feedback

In total, 28 participants from 4 universities participated in the course and once again feedback from the participants was collected through a survey conducted after the course. Overall, the participants were highly satisfied with the course, rating it 5.63 on a scale from 1 to 6 (11 responses). When asked if the programme content was relevant and applicable it rated 5.7 on a scale from 1 to 6.

Feedback from the programme illustrated that participants welcomed the time, space and structure to focus on their own programmes and to work together to self-assess their programmes within the CDIO framework. The need to fundamentally tie programme material to learning objectives and to make students aware of these learning objectives was also crystallised during the development programme. A common theme from participant's feedback was the valuable discussion on how student project work is/could be assessed, how feedback is/could/should be provided and at which stage during a project feedback is most beneficial to the students. Some feedback suggested that because the topics had generated much discussion, that more time in the programme could have been allocated to round table or open floor Q&A to learn from others experiences.

Participants were asked, through survey, which items from the development programme they would apply in their programme/courses, the overwhelming response was different techniques of feedback in courses and projects. All participants of the survey indicated that they intend to examine feedback system within their programme/module post discussions arising from the faculty development programme. How feedback could be altered to be more meaningful to the students, more formative for the students, but also how it could be given by student-to-student and facilitate the lecturer to focus on other aspects of the module.

Participants were also asked what steps they need to make desired change within their programme, responses here varied from establishing working groups within department, to informal communication with colleagues, to support from technical staff and faculty. However the common theme indicated by these responses to help make change within programmes then open communication channels between academics within universities is a fundamental requirement.

DISCUSSION

A two-day programme including fully aligned learning objectives for a faculty course has been created and lectured twice. However, there are several more, as important, outcomes from this, and they will be discussed here.

Through these courses, an awareness and opportunity was created for the faculty members teaching in raw materials MSc education to think about the underlying benefits of implementing CDIO within their course and programme. Also, this kind of course shows intensive examples from successful implementation of CDIO, which can motivate the participant in taking the next step to change. In order to continue working with such change, commitment is required from individual universities and other stakeholders to continually develop these aspects of their programmes and course.

The CDIO framework, as expressed in the syllabus and standards, gives general guidelines to review and develop engineering education in terms of product, processes, and systems development. The fact that the raw materials sector, at least within the secondary resources (substitution and recycling), to a large extent also deals with such terms, it implies that adoption of CDIO to the Raw materials education will be correspondingly possible. At the same time it will require some alteration in adoption, especially in the primary resource sector (exploration, mining, etc.) and at this point of time it cannot be fully estimated to what extent it can be adopted. The process of translation and transformation will also produce new knowledge and ways of implementation, which is potentially, a contribution back to the CDIO community.

There are many resources and examples available through the CDIO community to show application of design-implement projects for product-based applications, but comparatively fewer examples relevant to process oriented applications. This poses a challenge for raw materials related courses to develop effective project-based learning experiences within process oriented courses. Introducing the CDIO approach to raw materials programs poses a wide scope for development of unique pilot case studies, laboratory and workshop development, and collaborative teamwork exercises. Raw materials related industrial and technological involvement together with the CDIO syllabus would play an important role in the development of such exercises.

The feedback from the two courses' show that the participants appreciated the experience within the CDIO community, and felt that the examples showing successful implementations were highly motivating. This finding is consistent with other reports in the literature (Farmer, 2004; Loyer *et al*., 2011; Chuchalin *et al.*, 2015; McCartan *et al.*, 2016). However, an additional observation made here is that the participants appreciated the dedicated time and session for working with their own programmes and courses. The utility of such courses will increase when the participants are underway making improvements in their own programmes and courses. Conducting the course in workshop format, to include time and support for participants' own projects, will likely further develop this particular aspect. The documented results can then also serve to ensure that the learning outcomes of the course are met.

The participants from RM universities expressed the opinion that the CDIO implementation is a long-term process, especially at programme level. There are constraints from different universities' strategies and systems when it comes to changing programmes and courses, which is also highlighted from research by Malmqvist *et al.* (2008). There is a need for a continuous training of teaching faculty within the CDIO initiative to get a better consensus on developing programme and courses in RM. On a higher level impact, the CDIO initiative fits very well on meeting the goals and vision of EIT Knowledge and Innovation Community (KIC) and can substantially be linked to a long term growth in terms of competence development. Further, this will lay foundation for long term innovation within education system of RM by building sustainable relationship between industry and education; by involving students with real time project experience from industry; and helping in equipping engineers with ad-on skills of business, communication, critical thinking, and entrepreneurship.

Future Work

The developed faculty course is a two-day course for introducing participants to CDIO. To get more faculty involved; and to enable sustainable programme and course development at different participating universities, a longer period with CDIO is warranted. The faculty development course will be extended to a workshop format where the participant can bring their own programme and courses and can apply CDIO principles under the mentorship of CDIO leaders. This is currently included in module 3 (M3) of the course, see Table 2. With the development of cases and experience from the RM sector, new case studies of direct relevance will be featured in the course. The course/workshop promotion is also an important aspect when it comes to increasing the number of interested participants, to leverage the impact of this activity.

CONCLUSION

Chalmers University of Technology, Sweden and University of Limerick, Ireland jointly developed and organised two successful faculty development course given at the two respective locations. The course was designed to provide support to the various universities involved in providing programmes, across the entire value chain of raw materials. The modular CDIO faculty development course provides the benefit of being flexible in terms of organisation and delivery. This serves as a sustainable course with built-in ability to expand and customize while ensuring the same learning outcomes. This paper can be used as a reference for further development and implementation of the CDIO initiative in other disciplines. In order to drive a continuous development and creation of sustainable education in RM with true industrial involvement, a longer commitment of CDIO Initiative support is needed. This will further require wider faculty training with CDIO pedagogics, innovative laboratory development, and industry-driven project course development within RM.

REFERENCES

Allinson, R., Izsak, K., & Griniece, E. (2012). Catalysing Innovation in the Knowledge Triangle. *Practices from the EIT Knowledge and Innovation Communities*.

Berggren, K., Brodeur, D., Crawley, E., Ingemarsson, I., Litant, W., Malmqvist, J., & Östlund, S. (2003). CDIO: An international initiative for reforming engineering education. *World Transactions on Engineering and Technology Education, 2*(1), 49-52.

CDIO Syllabus 2.0 | Worldwide CDIO Initiative. (2017). Cdio.org. Retrieved 3 January 2017, from http://cdio.org/benefits-cdio/cdio-syllabus/cdio-syllabus-topical-form

CDIO Standard 2.1 | Worldwide CDIO Initiative. (2017). Cdio.org. Retrieved 3 January 2017, from http://cdio.org/content/cdio-standard-21

Chuchalin, A. Tayurskaya, M., & Malmqvist, J. (2015). Development of CDIO Academy in Russia. *Proceedings of the 11th International CDIO Conference*. Chengdu, China: Chengdu University of Information Technology.

Crawley E. F., Malmqvist J., Östlund S., Brodeur D. R., & Edström K. (2014). *Rethinking Engineering Education: The CDIO Approach* (2nd ed.) New York: Springer.

Crawley, E. F., Malmqvist, J., Lucas, W., & Brodeur, D. (2011). The CDIO Syllabus v2.0 An Updated Statement of Goals for Engineering Education. *Proceedings of the 7th International CDIO Conference*. Copenhagen, Denmark: Technical University of Denmark.

Edelbro, C., Hulthén, E., Clausen, E., O'Donoghue, L., Herrera, J., Jonsson, K., Bealieu, S., Aldert Kamp, A., & Försth, M. (2017). European initiative on CDIO in raw material programmes. Paper submitted to the 13th International CDIO Conference, Calgary, Canada, June 18-22, 2017.

Edström, K. & Kolmos, A. (2014). PBL and CDIO: complementary models for engineering education development. *European Journal of Engineering Education, 39*(5), 539-555.

Farmer, E. A. (2004), Faculty development for problem-based learning. *European Journal of Dental Education*, *8*(2), 59–66.

Kozanitis, A., Kwee Huay, H., Singh, M., Hermon, P., Edström, K., & Lei, H. (2009). Exploring Different Faculty Development Models that Support CDIO Implementation. *Proceedings of the 5th International CDIO Conference*. Singapore: Singapore Polytechnic.

Loyer, S. & Maureira, N. (2014). A Faculty Teaching Competence Enhancement Model: A Mentoring Approach. *Proceedings of the 10th International CDIO Conference*. Barcelona, Spain: Universitat Politècnica de Catalunya.

Loyer, S., Muñoz, M., Cárdenas, C., Martínez, C., Cepeda, M., & Faúndez, V. (2011). A CDIO Approach to Curriculum Design of Five Engineering Programs at UCSC. *Proceedings of the 7th International CDIO Conference*. Copenhagen, Denmark: Technical University of Denmark.

Malmqvist, J., Gunnarsson, S., & Vigild, M. E. (2008). Faculty professional competence development programs – Comparing approaches from three universities. *Proceedings of the 4th International CDIO Conference*. Gent, Belgium: Hoogeschool Gent.

McCartan, C., Hermon, J., Georgsson, F., Björklund, H., & Pettersson, J. (2016). A Preliminary Case Study for Collaborative Quality Enhancement. In J. Björkqvist, K. Edström, R. J. Hugo, J. Kontio, J. Roslöf, R. Sellens, & S. Virtanen (Eds.), *Proceedings of the 12th International CDIO Conference* (pp. 140-153). Turku, Finland: Turku University of Applied Sciences.

Ranga, M., & Etzkowitz, H. (2013). Triple Helix systems: an analytical framework for innovation policy and practice in the Knowledge Society. *Industry and Higher Education*, *27*(4), 237-262.

Smith, T. & Ingersoll, R. (2004). What Are the Effects of Induction and Mentoring on Beginning Teacher Turnover?. *American Educational Research Journal*, *41*(3), 681-714.

BIOGRAPHICAL INFORMATION

Kanishk Bhadani is a PhD student at the Department of Industrial and Materials Science, Chalmers University of Technology. His current research focuses on optimization in minerals processing.

Erik Hulthén is an Associate Professor in Product Development and Director of Masters Programme in Product Development at the Department of Industrial and Materials Science, Chalmers University of Technology. His current research focuses on optimization of crushing plants (for raw materials).

Johan Malmqvist is a Professor in Product Development and Dean of Education at Chalmers University of Technology, Göteborg, Sweden. His current research focuses on information management in the product development process (PLM) and on curriculum development methodology.

Catrin Edelbro is a Senior Lecturer in Mining and Rock Engineering at the Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology. Since January 2015 she also serves as the head of undergraduate education as well as deputy head at the Department of Civil, Environmental and Natural Resources Engineering. In this role she is responsible for the performance, quality and development of more than 20 degree programmes.

Alan Ryan is a Lecturer in Sustainable Automation and programme director for Common Entry Engineering at the University of Limerick, Ireland. His current research focuses on water and energy recovery and reuse within the dairy processing sector

David Tanner is a Senior lecturer in Manufacturing Process Technology at the University of Limerick and was recently appointed as Assistant Dean of Internationalization in the Faculty of Science and Engineering. Dr Tanner has been a member of CDIO since 2009.

Lisa O'Donoghue is a Senior Scientist and Metallurgist affiliated with the Department of Engineering at the University of Limerick and European Institute of Innovation and Technology – EIT- Raw Materials North AB based in Luleå, Sweden.

Kristina Edström is an Associate Professor in *Engineering Education Development* at the School of Education and Communication in Engineering Sciences, KTH Royal Institute of Technology, one of the founding members of the CDIO Initiative. Her current research takes a critical approach to the "why", "what" and "how" of engineering education reform.

Corresponding author

Kanishk Bhadani
Department of Industrial and Materials Science
Chalmers University of Technology
Campus Johanneberg, Hörsalsvägen 7A
SE- 41296 Göteborg, Sweden
+46 3177 250 03
kanishk@chalmers.se