Experiences in CDIO Methodology in Mining Engineering and Civil Engineering

J.A. Ramirez Masferrer[1], J. Herrera Herbert[2], P. Kindelan Echevarría[3], J.A. Velázquez Iturbide[4]
j.ramirez@upm.es, juan.herrera@upm.es, kmanga_009@yahoo.es, angel.velazquez@urjc.es

[1]Ingeniería Civil Construcción Infraestructura y Transporte
Universidad Politécnica de Madrid
Madrid, España

[2]Ingeniería Geológica y Minera
Universidad Politécnica de Madrid
Madrid, España

[3]Lingüística Aplicada a la Ciencia y Tecnología
Universidad Politécnica de Madrid
Madrid, España

[4] Escuela Técnica Superior de Ingeniería Informática
Universidad Rey Juan Carlos
Madrid, Spain

Abstract- Often students believe that engineering studies are too difficult or that it takes a very special intelligence or preparation to undertake them successfully. EIT - Raw Materials, seeking future professionals adapted to current new environments, develops educational projects implementing the CDIO initiative (Conceive - Design - Implement - Operate), which enhances learning and helps students learn while enjoying themselves. The idea is to awaken their interest by proposing the complete development of creative projects, applying the CDIO methodology guided by a tutor. The CDIO methodology emphasizes the foundations of engineering to solve problems. This study presents, experiences conducted since 2001 at Universidad Politécnica de Madrid (no sé si quieres mencionar las escuelas que lo están trabajando: Minas y Civil) and is focused on the current ones going on right now. These are being developed in an educational innovation project that is being carried out at the time this study is written, verifying that the methodology improves the interest of the students. students, and learning. The experience that is presented is done without any material aid or equipment provided to students or the use of any laboratory. Even so, the students manage to present very interesting solutions, of all kinds, including software and robotics. It is shown that students prefer practical activities than complex mathematical calculations.

Keywords: CDIO, Adaptative learning, Project Based Learning, Experimental Learning.

1. Introduction

The CDIO Initiative is an educational framework designed for engineering students, born with the idea of emphasizing the fundamentals of engineering itself (Conceive Design Implement Operate home page http://CDIO.org).

The word engineering and the base of CDIO are closely linked, since CDIO technology could be considered as the use of "ingenuity" to address (academically) real problems, using engineering and scientific principles.

The pioneers and other collaborators of the CDIO initiative adopt an international methodology, which has these four steps in the creative process: 1 / Conceive - 2 / Design - 3 / Implement - 4 / Operate (represented by its initials: CDIO) in the framework of curriculum planning and results-based assessment (Conceive Design Implement Operate home page http://CDIO.org).

The CDIO initiative has grown from four initial founding centers (MIT, Chalmers, KTH, and Linköping University) to a community of more than 130 institutions around the world. The collaborators of this initiative exchange experiences and practices learning from each other (Conceive Design Implement Operate home page http://CDIO.org), sharing knowledge on a day-to-day basis, and also through specific meetings and congresses.

CDIO learning is established around student-centered pedagogy, fostering project-based practical skills (Manna, S. Ghazal Sheikholeslami, G., and Nortcliffe, A., 2020), which, once enunciated by the teacher, the student must develop properly and under the tutelage of the teacher who acts as a guide.

All this information is detailed in the Proceedings of the XVI International CDIO Conference, which took place at the Chalmers University of Technology, Gothenburg, Sweden (June 8-10, 2020), which was attended by two of the authors of this study.

In addition, the CDIO methodology encourages students to follow the subjects more continuously, avoiding what academically speaking has come to be called "Bingeing and purging", in which students, shortly before the exam "binge" to study, dropping everything at the time of the exam (purge), even studying only the questions that usually fall or are repeated in the exams (Yew Fei Tang and Wilson, H., 2020). These short-term memory exercises prevent them from actually learning and acquiring the fundamental knowledge that they need in an engineering career.

The CDIO methodology fits perfectly into the learning associated with continuous assessment, to which all degrees are being adapted within the framework of the European Higher Education Area (EHEA).

Many authors consider that, within the strategy of encouraging the student to continuous learning, challenges are a fundamental part (Lavecchia, A. M., Lui, H. and Oreopoulos, P., 2016). , and therefore, technologies like CDIO collaborate in a very important way in the process.

In the words of Richard Feyman: Students should be encouraged to think, doubt, communicate, learn from their mistakes, and most importantly, have fun.

2. CONTEXT

There are many project-based learning experiences such as those shown in the work of Petersen & Nassaji (Petersen, C. and Nassaji, H., 2016). or problem-based learning such as those shown in the Savery studies (Savery, J., 2006) or in experiential learning presented in the McDonald & Spence studies (McDonald, M. and Spence, K., 2016).

As Konak, Clark, & Nasereddin present, experiential learning promotes many practical skills in students (Konak, A., Clark, T., and Nasereddin, M. 2014) and all of them are the basis of the CDIO work presented in the Ye & Lu studies (Ye, W. and Lu, W., 2011). and also Konak, Clark & Nasereddin (Konak, A., Clark, T. and Nasereddin, M. 2014).

In the bibliography, multiple experiences can be found within the CDIO framework, such as that of the academic team of Canterbury Christ Church University (Manna, S. Ghazal Sheikholeslami, G., and Nortcliffe, A., 2020) with engineering courses, through creative projects, whose idea is to make students realize that they can design a complex project from a simple idea (Manna, S. Ghazal Sheikholeslami, G., and Nortcliffe, A., 2020).

In some cases, an attempt has been made to detect with surveys the reason that some engineering students did not feel prepared to face this career, or felt serious difficulties in this regard, even causing failure and/or abandonment of studies. Generally, the same students consider that engineering is difficult, that they are studies that involve considerable effort and time, or that they do not have a sufficient basis in basic subjects, such as, for example, in mathematics; even that only the very intelligent could study engineering, notably decreasing interest in these branches and also enrollment, as argued by Manna, Ghazal Sheikholeslami & Nortcliffe (Manna, S. Ghazal Sheikholeslami, G., and Nortcliffe, A., 2020).

It is known that, when students apply the CDIO methodology, they develop critical thinking about real-world problems, work as a team, implement (develop and specify) their ideas (Manna, S. Ghazal Sheikholeslami, G., and Nortcliffe, A., 2020) and it is appreciated that this encourages them to acquire new knowledge.

Some authors show that students prefer to see innovative engineering projects, instead of complex mathematical calculations and equations, which is why these types of manual projects (to call them somehow) tend to attract the student and give good results (Manna, S. Ghazal Sheikholeslami, G., and Nortcliffe, A., 2020).

It has been shown that after developing a CDIO project, students are more interested in engineering studies (from 25% to 75%), and after developing the CDIO project, more students continued engineering studies, and the number increased. of questions in class, (Manna, S. Ghazal Sheikholeslami, G., and Nortcliffe, A., 2020). Likewise, the fact that participation increases are associated with an increase in general interest in engineering subjects.

A. CDIO in Mining Engineering and Civil Engineering.

The increasing complexity of mining operations makes the study of Mining Engineering increasingly demanding, demanding broad sets of skills to achieve new profiles of professionals, adapted to today, and capable of managing changes, (Herrera Herbert, J., and Ramirez Masferrer, JA, 2019)

The production of raw materials is adapting at high speed to the new digital revolution, which will make few very efficient professionals manage remote or automated systems, highly adapted to recycling, environmental care, with databases, receiving and transmitting. environmental information, production, processing, etc.

The change that is taking place around raw materials modifies the extractive sector, making it similar to the most advanced industries. This means that the sector where it is obtained has to be transformed, increasing efficiency, being less wasteful, reducing energy consumption, and increasing respect for the environment, with professionals adapted to this new, more varied, changing, and complex environment.

a. EIT Raw Materials and their support for CDIO

The European Institute of Innovation and Technology (EIT) was created in 2008 as a unique initiative of the European Union to boost innovation and entrepreneurship across Europe. This institute supports, among others, the development of partnerships between Universities, university-business collaboration (Knowledge and Innovation Communities - CCI).

The EIT - Raw Materials is par excellence, the European institute most related to the extraction and studies of resources and raw materials.

In EIT - Raw Materials, more than 120 European partners, industries, and universities from more than 20 countries of the European Union participate.

EIT Raw Materials is the largest consortium in the raw materials sector worldwide; having partners who participate in all phases of the raw material production chain, from exploration to start-up, through efficient and sustainable mining, and through mineral processing, recycling, circular economy, etc.

EIT Raw Materials maintains the idea of turning raw materials into one of the main strengths of Europe, seeking new solutions promoting competitiveness, growth, and new educational approaches in the sector (EIT Raw Materials. Developing Raw Materials into a major strength for Europe, 2018).

With the support of EIT Raw Materials, educational projects have been developed that implement CDIO methodology in careers related to mining exploration, mineral processing, and metallurgy (Herrera Herbert, J. and Ramirez Masferrer, JA, 2019), seeking professionals adapted to the new current environments, and adaptable to those of the future.

The European Commission chooses to support this type of project. Specifically, part of the professors that make up the Educational Innovation Group "Innovatio Educativa Tertio Millennio" of the Polytechnic University of Madrid participates in two European projects: The first one started in 2016 with the following partners: Luleå Technological

University (Sweden), Chalmers University of Technology (Sweden), Technical University of Clausthal (Germany), Polytechnic University of Madrid (Spain), University of Limerick (Ireland), Luossavaara-Kiirunavaara AB - LKAB (Sweden), RUSAL Aughinish Alumina (Ireland), Technological University from Delft (Netherlands) and SP Sveriges Tekniska Forskningsinstitut AB (Sweden); and another in 2018, formed by a consortium between the Technological University of Chalmers (Sweden), the Polytechnic University of Madrid - UPM or Technical University of Madrid (Spain), the Technological University of Luleå - LTU (Sweden), Clausthal University of Technology - CUT (Germany), University of Limerick - UL (Ireland), Luossavaara-Kiirunavaara Aktiebolag LKAB (Sweden) and RISE - Swedish Research Institutes.

In the raw materials and Civil Engineering sector, technological developments related to the integration of sensors, modern information and communication systems (ICT) and artificial intelligence (AI) will only lead to revolutionary innovations, if they also incorporate social acceptance and environmental, respect regulatory limitations and adapt to social impact (Clausen, E., Edelbro, C., Herrera Herbert, J., Edström K. and Jonsson, K., 2017). For this reason, the development of real projects in teaching, as proposed by CDIO, is part of the teachings of the 21st century in this field.

3. DESCRIPTION

The ElT promotes the innovative educational framework of the CDIO initiative and emphasizes the fundamentals of engineering. Future professionals with a mentality of innovation, entrepreneurship, sustainability, and quality are sought, based on a circular economy and respect, as well as a deep knowledge of the discipline in which the experience is incorporated.

The exercises proposed, from 2001 to the present, by the professors who participated in this project have tried to promote the triangle "industry, engineers and students", therefore, in them, students are encouraged to consult specialized companies or to active engineers.

a. Previous experiences

The first CDIO-type experience that the group of teachers, who currently form the Educational Innovation Group "Innovatio Educativa Tertio Millennio" developed, was in 2001 at the Higher Technical School of Mining Engineers of the Polytechnic University of Madrid, proposing to the students, an optional structure contest, in which 45 students participated.

In this first experience, the statement was directly a "challenge" in which it was necessary to build in light wood (balsa wood), with glue joints, a structure that would save a span (distance between supports) of 120 cm, being the weight structure maximum 300 g.

Structures were loaded to failure. The winner weighed 145g and resisted 22 kg, that is, more than 151 times its own weight (almost 152 times). The students were enthusiastic about the challenge. A summary book was published of the work of the students who wished it (25 works) [Figure 1], and the reception of the activity on their part was splendid, before, during and after it, obtaining very good evaluations of the work, affirming that it had helped them to learn and to consolidate concepts.

Figure 1: Cover image of the book "Tournament of structures".

The echo of this activity reached the national press, and the newspaper "El Mundo" published a full-page article about the professor entitled "El Ingeniero total" (“The Total Engineer” in Spanish) (https://www.elmundo.es/campus/2002/03/07/ultima/CAM220732_1.html).

As a second experience, the following year, the challenge was repeated, this time with towers, also accepting paper as a construction material.

This was also very well received by the students, who learned and enjoyed it.

The third experience of this group of professors took place in 2009 at the School of Public Works Technical Engineers (currently the Higher Technical School of Civil Engineers) of the Technical University of Madrid - UPM. This time it was about creating a machine that would perform a series of movements of a half kg weight (vertical and horizontal movements).

The students not only learned but enjoyed themselves. Subsequently, a DVD was published [Figure 2] with this experience, and some of the solutions that "Conceived, Implemented, Developed and Operated" have been used in later courses to explain the principle of the subject "Machinery and auxiliary means".

Figure 2: Frame from the DVD “La Maquina”.

The fourth experience took place in the same School, and it was also about machines. This time they were the ones moving using the potential energy of a standard mass. Later they were subjected to competitions in pairs (one trying to displace the opposite) until they got a winning machine.

Without hardly realizing it, the students, not only during the development of their machine, but also while observing the competition, established knowledge of the entire subject, such as power, energy, mechanisms, grip on the ground, and so on.

b. Recent experiences 2019-2020 and 2020-2021

Following this line of experiences, the Universidad Politécnica de Madrid – UPM (Technical University of Madrid) granted an Educational Innovation project to the Educational Innovation Group "Innovatio Educativa Tertio Millennio", for the development of its own CDIO projects in the classroom, in Mining Engineering and Engineering subjects. Civil.

CDIO projects usually have the statement of a specific problem to be solved. But in the case presented in this study, the statement was much more open, since it was the student himself who, in a first phase, looked for the problem that he wanted to tackle using his CDIO methods.

As it is intended that the student see the inventive and development process as a challenge, the statement ends with an interesting challenge "Yes. You can be the next Steve Jobs."

Once the student has chosen the exercise, the teacher uses one hour of class to present it, and explain the methodologies of the CDIO method, encouraging them to follow the Conceive - Design - Implement - Operate path.

Sometimes, students are unaware of current innovations, so in the presentation of the exercise, they are given as an example, the most avant-garde, and research and engineering projects developed around the world. This increases their level of interest (Manna, S. Ghazal Sheikholeslami, G., and Nortcliffe, A., 2020).

The exercise is compulsory, so all the students (in teams of between 2 and 4) begin to work, with the assistance of a tutor, who in turn will try to make them carry out the process, not follow directly the teacher's recommendations.

Of the 20 groups (Academic period 2020-2021), 15 were 4 students, 4 were three, and one was 2, with 74 students completing the exercise.

About 30 days after putting the statement, and having attended the optional tutorials that they wish, all teams make a first presentation, and the teacher corrects it, scores them, and guides them.

Since in the academic period 2020-2021 the classes of the subject "Machinery and Auxiliary Means" of the Degree in Civil Engineering (UPM) have been non-face-to-face, the presentation of the CDIO work by the student, and the first scoring correction by the professor, it has been through a forum on the Moodle platform, which, in principle, could have the advantage that students can consult the professor's comments and the corrections to all groups at any time; Although it has been observed that this is not really achieved, since each student is interested in the correction that they make to their group, and not in those that the teacher makes to other workgroups. Asked about their lack of interest in learning with the correction from other groups, they usually state that they do so due to a lack of time to dedicate to the subject.

In this first correction, it is observed that approximately 30% of the groups have chosen challenges that the teacher considers very interesting, 35% interesting, 20% appropriate and 15% can rethink their topic of work. About 7% start over on another topic.

The analysis of the groups that have to rethink their subject is very interesting. There are basically two types: About 2/3 of these are usually very superficial jobs, that is, there is clearly little dedication of the students, so it is appropriate for them to forget the little work they have done, and what Rethink again from scratch, and the remaining 1/3, perhaps somewhat more worrying, are groups that raise fanciful ideas, that contradict the basic principles of physics, or with serious errors of magnitude. For example, statements that contradict the principles of thermodynamics. An engineering student who proposes solutions in which the energy comes out of nowhere or mechanisms similar to perpetual mobiles is worrying.

The second delivery another 75 days later, (counting the days of Christmas holidays) was already the final one. Between the two deliveries, the teacher attends the students in tutorials, guiding them about the work. The presentation by the student teams, who had carried out the work, raised great interest since the ideas and their development were truly admirable. Seeking to awaken their ingenuity, the teacher allowed them to present only for 5 minutes, and 5 minutes of questions (as the saying goes, "The good, if short, twice good").

4. Results

Regarding the problem to be solved, being free did not necessarily have to be related to engineering, however, it is observed that the issues related to it increase in the final installment (the 2nd) [Figure 3].

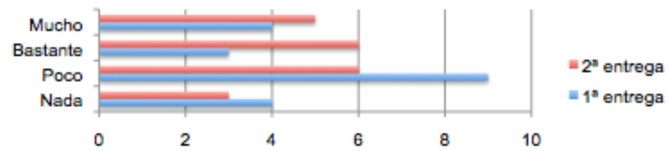

Figure 3: Engineering-related topics.

Many students managed to finish a functional scale model (7 groups), and most built something, used computer programs, or programmed very interesting solutions, as shown in [Figure 4].

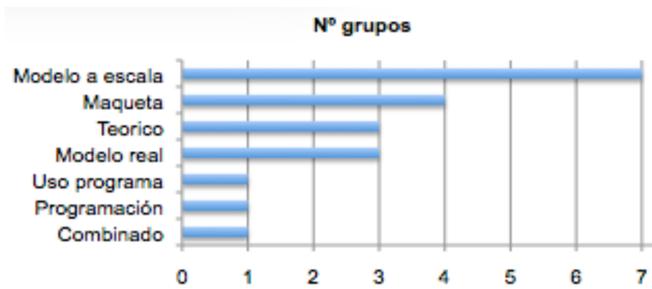

Figure 4: Type of exercises submitted by each group.

It has been observed that in the first installment, many students do not get to develop the complete process (Conceive - Design - Implement - Operate); only 5 completed it, and there were even 6 groups that did not complete any of the phases, but in the second installment, almost all managed to complete them (17 of 20 groups), as shown in [Figure 5].

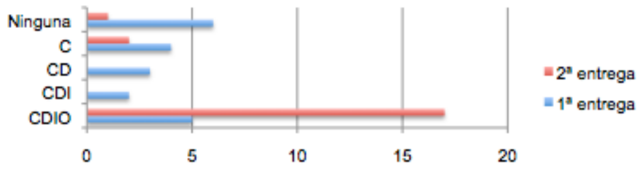

Figure 5: CDIO phases completed in each group.

The first impact detected has been the perceived interest of the participants, since, without an economic budget, they have done impressive work. Some programming, others presenting functional models, even with small computers (Arduino) with robotics actions, others simply very ingenious mechanisms, and in general, showing that they had learned a lot.

As a second impact, it has been detected that some students have served to correct misconceptions they had. For example, some had raised ideas that did not comply with the principles of thermodynamics, and it has helped them to understand them.

A third impact is that the students understand better, after the exercise, the concepts that have been explained in the theoretical topics of the subject. By applying them or by seeing in a presentation of other groups how others apply them, they understand them much better.

More than 90% of the delivered exercises adequately separate the Conceive - Design - Implement - Operate phases. Although the last phases are not fully developed in three of the twenty projects presented, analyzing the reason, it is concluded that it is usually because an operational prototype is not built. It should not be forgotten that students do this exercise without any kind of financial support, and they are not asked to consume any of their resources. With these limitations, it is difficult to implement and operate prototypes, although some have developed some very interesting ones, even with recycled waste material.

After presenting the exercise in class, the students show that they feel comfortable with the freedom they initially had in choosing the topic and developing it, and that, after approximately two months to solve it, they consider themselves more capable of contributing proposals and solutions in modern life, considering themselves more creative, and, in their own words, “more inventors”.

Finally, it is observed that some works are computer programs made by students or developments in the educational use of an existing program; It should be studied whether it is because they carry out the exercise without the financial support of any kind (since programming has a low economic cost). It is also added that subsequent research should delve into how this lack of financial support affects the exercises presented.

5. Conclusions

The development, in the Continuous Assessment, of CDIO projects, has shown that student learning increases considerably. It is appreciated that, in large part, this is due to the interest that these academic exercises in the development of real projects arouse in the students.

In the examples presented of the CDIO projects, it has been possible to develop a path between the educational project and the standard project of the engineering world.

In this area, it seems appropriate that the CDIO philosophy be applied in various subjects within the student's training, gradually bringing him closer to the real engineering world of the company.

Even so, the results invite us to conclude that the CDIO methodology should not only be applied in the subjects in which teachers are involved but, in general, associated with undergraduate and graduate studies. Further research should delve into this possibility.

Acknowledges

To the members of the Educational Innovation Group "Innovatio Educativa Tertio Millennio", who make this research possible.

To our students, without whom we would not improve.

To the Universidad Politécnica de Madrid (Technical University of Madrid) for supporting us, and providing us with the necessary means for these investigations.

References

Conceive Design Implement Operate home page. http://www.CDIO.org

Manna, S. Ghazal Sheikholeslami, G., and Nortcliffe, A. (2020) Developing engineering growth mindset through CDIO outreach activities.

Petersen, C. and Nassaji, H. (2016). Project-Based Learning through the Eyes of Teachers and Students in Adult ESL Classrooms. Canadian Modern Language Review, 72(1), pp.13-39.

Savery, J. (2006). Overview of Problem-based Learning: and Distinctions. Interdisciplinary Journal of Problem-Based Learning, 1(1).

McDonald, M. and Spence, K. (2016). Experiential Learning: Impacting Student Lateral and Vertical Development. Sport Management Education Journal, 10(2), pp.140-147.

Ye, W. and Lu, W. (2011). Case Study on CDIO-Based Engineering Education Mode through CollegeIndustry Linkages. Advanced Materials Research, 217-218, pp.819-823.

Konak, A., Clark, T. and Nasereddin, M. (2014). Using Kolb's Experiential Learning Cycle to improbé student learning in virtual computer laboratories. Computers and Education, 72, pp.11-22.

Yew Fei Tang and Wilson, H. (2020) Investigating repeatable nudge effects with spaced repetition in use MCQs

Lavecchia, A. M., Lui, H. and Oreopoulos, P. (2016). Behavioral Economics of Education: Progress and Possibilities. In: E. A. Hanushek, S. Machin & L.

Woessmann, eds. Handbook of the Economics of Education Vol. 5. Elsevier, (pp. 1-74).

Herrera Herbert, J. and Ramirez Masferrer, J.A. "Implementation of Conceive – Design – Implement – Operate in Mining Engineering Education Programs". Proceedings of INTED 2019 Conference, Valencia, Spain, (March 2019) ISBN: 978-84-09-08619-1.

EIT Raw Materials. Developing Raw Materials into a major strength for Europe. Accessed 28 December 2018. Retrieved from https:// eit.europa.eu/eit-community/eit-raw-materials

Clausen, E., Edelbro, C., Herrera Herbert, J., Edström K. and Jonsson, K. "Implementation of CDIO in Mining Engineering Education", 28th SOMP Annual Meeting and Conference, 2017. ISBN: 978-88-6378-004-8

https://www.elmundo.es/campus/2002/03/07/ultima/CAM220732_1.html