SPREADING THE MODEL: CDIO OF CDIO COURSES USING CREATIVITY TECHNIQUES

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ABSTRACT

The CDIO approach to engineering education has reformulated higher education in scientific, technical and technological disciplines, through the promotion of active learning in connection with the conception, development, implementation and operation of real engineering products, processes and systems. The model is already making a transformative impact worldwide in more than 120 universities that collaborate and learn together. However, spreading the model is a challenging issue as, in spite of the verified clear benefits of shifting to CDIO-related teaching-learning methodologies and of the efforts of CDIO members, for continuously supporting potential new partners in their endeavors, transforming engineering education and motivating professors to change their way of teaching is always a complex and extremely multifaceted process. The CDIO standards provide a comprehensive set of aspects, which should be tackled when trying to incorporate the CDIO model to an already existing engineering degree or set of degrees, or when trying to design a new programme accordingly. The workshops from the CDIO conferences and the published papers of the CDIO proceedings also constitute a relevant source of information and inspiration. Nevertheless, in some cases, professors wishing to conceive, design, implement and operate new courses, based on the CDIO model, may possibly feel overwhelmed by the required dedication or even find difficulties when facing the process of reinventing or creating a course following the model. Reluctance of professors to change and their doubts when trying to create CDIO-related courses are among the common factors that can limit the further expansion of the CDIO model.Trying to develop a systematic approach to “the CDIO cycle of innovative CDIO courses” we present a set of creativity promotion canvases (one for each stage of the process) adapted to the strategic planning of novel engineering courses following the CDIO approach. The “conceive” canvas helps professors to match the learning objectives of the course with the type of engineering products, processes or systems to be developed. The “design” canvas guides professors through a process of matching outcomes with topics and activities and supports through the analysis of requirements for the application projects. The “implement” canvas focuses on the resources needed for developing the projects and connects topics and lessons with the steps of the project to be developed. The “operation” canvas concentrates on key processes during the real implementation of the course, including group formation, teamwork promotion, conflict solving, coordination of participants, including professors, and evaluation. The application of these user-friendly creativity promotion canvases is explained through a real case study and its potential illustrated by the results of their application to strategically planning a set of CDIO courses with a group of 30 professors in a Spanish university.

KEYWORDS

Continuous Improvement of Education, Faculty Development, Change, Standards 9, 10

INTRODUCTION

The CDIO approach to engineering education has reformulated higher education in scientific, technical and technological disciplines, through the promotion of active learning in connection with the conception, development, implementation and operation of real engineering products, processes and systems (Crawley, 2007). The model is already making a transformative impact worldwide in more than 120 universities that collaborate and learn together. However, spreading the model is a challenging issue. In spite of the verified clear benefits of shifting to CDIO-related teaching-learning methodologies and of the efforts of CDIO members, for continuously supporting potential new partners in their endeavors, transforming engineering education and motivating professors to change their way of teaching is always a complex and extremely multifaceted process. The CDIO standards provide a comprehensive set of aspects, which should be tackled when trying to incorporate the CDIO model to an already existing engineering degree or set of degrees, or when trying to design a new programme accordingly. The workshops from the CDIO conferences and the published papers of the CDIO proceedings also constitute a relevant source of information and inspiration.

In fact, according to our experience, becoming member of the International CDIO Initiative and fostering CDIO-related methodologies within a university is a much more straightforward process than those linked to getting engineering programmes of study accredited by most international accreditation agencies and boards. Nevertheless, in some cases, professors wishing to conceive, design, implement and operate new courses, based on the CDIO model, may possibly feel overwhelmed by the required dedication or even find difficulties when facing the process of reinventing or creating a course following the model. Reluctance of professors to change and their doubts when trying to create CDIO-related courses are among the common factors that can limit the further expansion of the CDIO model. Since the incorporation of UPM to the International CDIO Initiative in 2015, our team has been involved in the creation of several CDIO courses in 5 engineering programmes (Díaz Lantada, 2014, 2015, 2016, Lumbreras Martín, 2015, 2016). We have also taken part in different seminars, workshops and international design competitions and schools, in which we have supported colleagues to get familiar with the basics of the CDIO model and to plan project-based learning courses in varied fields of engineering. In this period, we have understood that innovative methodologies are attractive and rewarding. However, in some cases, easy-to-use resources for training engineering educators may help to expand innovative methodologies.

Trying to develop a systematic approach to "the CDIO cycle of innovative CDIO courses" we present a set of creativity promotion canvases (one for each stage of the process) adapted to the strategic planning of novel engineering courses following the CDIO approach. The "conceive" canvas helps professors to match the learning objectives of the course with the type of engineering products, processes or systems to be developed. The "design" canvas guides professors through a process of matching outcomes with topics and activities and supports through the analysis of requirements for the application projects. The "implement" canvas focuses on the resources needed for developing the projects and connects topics and lessons with the steps of the project to be developed. The "operation" canvas concentrates on key processes during the real implementation of the course, including group formation, teamwork promotion, conflict solving, coordination of participants, including professors, and evaluation. The application of these user-friendly creativity promotion canvases is explained through a real case study, linked to a course on "Design and manufacturing with polymers", and its potential illustrated by the results of their application to strategically planning a set of CDIO courses with a group of 30 professors in a Spanish university.

CREATIVITY PROMOTION CANVASES FOR THE CDIO OF CDIO COURSES

In order to support the systematic promotion of the CDIO model, a set of creativity promotion canvases or templates has been developed for the conception, design, implementation and operation of CDIO courses. One canvas is designed for each stage of the process, according to main questions, unknowns and challenges that typically arise during the creation of project-based and CDIO-related teaching learning experiences. The canvases help developers (higher education professors in this case) to systematically consider the key aspects of the challenge being tackled (new CDIO courses). These templates operate in a similar way to other design or creativity promotion canvases from different engineering disciplines, such as those used in the well-known business model generation methodologies (Osterwalder, 2010). According to our experience with novel CDIO courses, the most straightforward approach to the CDIO of CDIO experiences relies on systematically planning the teaching-learning experience. From the very beginning (and in parallel) one should consider, both the desired learning objectives, professional outcomes and topics of the course, together with the engineering project that will help to articulate the experience, to apply the acquired knowledge and to promote the objective professional skills. Table 1 summarizes the driving questions that have helped in the design of the creativity promotion canvases. We consider such questions to be the more relevant one can ask, for the straightforward and reliable conception, design, implementation and operation of innovative CDIO courses. In our view, systematically considering and answering such questions, before the first implementation of a new CDIO course (and counting with the support of the CDIO canvases explained in the following section), helps to successfully replicate the model.

Table 1. Summary of questions and challenges that typically arise in new CDIO experiences

Stage	Questions linked to the CDIO course	Questions linked to the related CDIO project
C	-Which are the learning objectives of the course? -Which is the social and industrial context of the course?	-Which engineering systems benefit from the course? -Which engineering system are the students going to project?
D	-Which are the professional outcomes we would like to promote? -Which are the thematic blocks of the course?	-Which are the requisites for the CDIO projects and for students? -How do the CDIO project stages relate to the thematic blocks?
I	-Which contents should be included in the course programme? -Which contents support the projects to be developed?	-How do the contents explained relate to the stages of the projects? -Which are the human and material resources required?
O	-Which are problems may arise and how can we solve them? -How is the course assessed and its progress monitored?	-How can we make the CDIO projects and experience sustainable? -How can we monitor and mentor the CDIO project to keep them in pace?

The four CDIO canvases, developed according to Table 1, are presented in the following pages (Figures 1-4) and illustrated by showing their application to a CDIO course on “Design and manufacturing with polymers”. In such course, students work in groups for designing toys with different polymeric components and following design for injection molding principles and for developing the production tools (molds) used for manufacturing such toys (Díaz Lantada, 2017). The course is taught at UPM (Master’s of Science in Industrial Engineering) since 2005.

CONCEIVE	Course: *Design and manufacturing with polymers*	Degree: *Master's Degree in Industrial Engineering*
	Academic year: *2nd (Mechanical Specialization, Master's level)*	Professors: *Andrés Díaz Lantada, Juan de Juanes Márquez*

SUMMARY OF EDUCATIONAL OBJECTIVES OF THE COURSE

I. Introduce students to the relevance of polymeric industry and polymers applications. Introduce main properties of polymeric materials.

II. Show the advantages of polymeric materials and related manufacturing processes to achieve competitive products for several industries.

III. Teach main strategies for the adequate design of polymeric components and of related manufacturing tools for injection molding.

IV. Teach main joining methods for polymeric components and explain related design and calculation processes.

V. Provide students with the relevant tools for their professional development as designers of polymeric components and products and as developers of manufacturing tools for the polymeric industry. Train them in the employment of resources used in industrial practice.

WHICH ENGINEERING SYSTEMS, PRODUCTS, PROCESSES REQUIRE THE PROFESSIONAL OUTCOMES THAT THE COURSE PROVIDES?

- Conventional products manufactured by injection molding of thermoplastic materials (house appliances, toys, housings of electronic products, tools, furniture…).

- Components of transport, medical and space industries, among others, in which injection molded thermoplastics are employed.

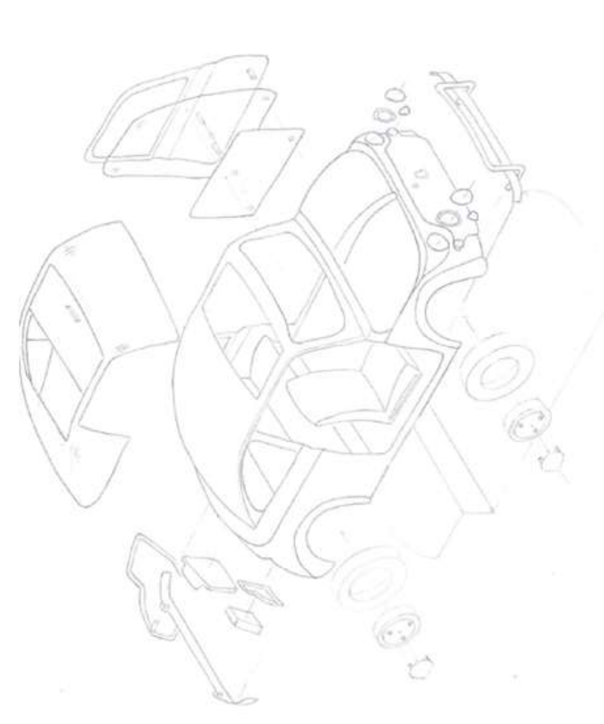
- Molds and tools for the injection molding manufacturing industry.

WHICH ENGINEERING SYSTEM ARE WE GOING TO DEVELOPE?

- Working in teams, students design a toy with different polymeric components (at least one component per team member). The components follow design for injection molding principles.

- Working in teams, students design the tools (molds) for the manufacture of the more significant components of the selected toy.

SCHEME OF PRODUCT / PROCESS TO COMPLETELY DEVELOPE DURING THE CDIO PROJECT-COURSE



Toy car (FIAT 500, 1967) designed for its manufacture using thermoplastics and injection molding.
Students: R. Larrañeta, M. Escolar, G. Rodríguez.

Figure 1. Creativity promotion canvas for the "Conceive" stage: Application to course on "Design and manufacturing with polymers".

DESIGN	Course: *Design and manufacturing with polymers*	Degree: *Master's Degree in Industrial Engineering*
	Academic year: *2nd (Mechanical Specialization, Master's level)*	Professors: *Andrés Díaz Lantada, Juan de Juanes Márquez*

ENGINEERING OUTCOMES TO BE PROMOTED DURING THE COURSE	
EUR-ACE®:	ABET:
■ Knowledge and comprehension □ Analysis in engineering ■ Engineering projects □ Research and innovation ■ Practical engineering application □ Judgment performance ■ Communication and teamwork ■ Lifelong learning	■ Ability to apply engineering knowledge □ Ability to design and perform experiments ■ Ability to design products and processes ■ Ability to work in multidisciplinary teams □ Ethical and professional responsibility ■ Ability to communicate effectively □ Broad education to understand impacts ■ Compromise with lifelong learning □ Knowledge of contemporary issues ■ Ability to use modern engineering tools

REQUISITES FOR THE CDIO PROJECTS TO BE DEVELOPED

- The CDIO project is linked to the complete development of a toy made of polymeric components; whose manufacturing tools (injection molds) should be also designed.

- Teams of 3 to 4 students.

- At least one significant polymeric component per student.

- CAD tools must be employed for the design of the different components and tools.

- Geometries and joints must be designed and optimized on the basis of explained theory and with the support of FEM and CAM modeling tools.

- Thermoplastic materials must be selected and compared employing resources used in industry for optimizing polymeric parts (i.e. Moldflow).

- The geometry-material-process triad must be considered for optimization purposes.

THEMATIC BLOCKS	PLANNED ACTIVITIES (for the CDIO projects)
I. Introduction to polymers and their industrial applications.	*- Selection and validation of polymeric materials for a selected toy.*
II. Design oriented to manufacture using polymeric injection molding.	*- Basic design of the different toy components.*
III. Design of joints between polymeric components in complex products.	*- Design and calculation of joints between polymeric components.*
IV. Design optimization considering: Geometries, materials and processes.	*- Optimization of geometries using mechanical and manufacturing simulations.*

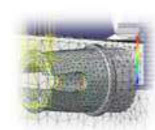
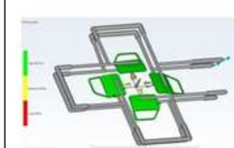
SCHEME OF STAGES AND EXPECTED RESULTS			
CONCEIVE	DESIGN	IMPLEMENT	OPERATE
			

Figure 2. Creativity promotion canvas for the "Design" stage: Application to course on "Design and manufacturing with polymers".

IMPLEMENT	Course: *Design and manufacturing with polymers*	Degree: *Master's Degree in Industrial Engineering*
	Academic year: *2nd (Mechanical Specialization, Master's level)*	Professors: *Andrés Díaz Lantada, Juan de Juanes Márquez*

PHASE	REQUIRED MATERIAL RESOURCES	REQUIRED HUMAN RESOURCES
Conceive	*Paper* *Pencil, marking pens* *Course bibliography*	*Students* *Professors*
Design	*Paper* *Pencil, marking pens* *CAD-CAE-CAM resources* *Course bibliography*	*Students* *Professors*
Implement	*Rapid prototyping techniques* *Rapid tooling techniques* *3D printing machines* *Vacuum casting equipment* *Machining equipment* *Commercial components (motors, batteries, standardized elements)*	*Students* *Professors* *Lab technicians (department)* *External lab technicians*
Operate	*Laboratory injection machine* *Molds with interchangeable parts* *Polymers for injection molding, if the whole cycle is to be fulfilled*	*Students* *Professors* *Lab technicians (department)* *External lab technicians* *Communication experts*

RELATIONSHIP BETWEEN SYLLABUES AND CDIO PROJECTS' STAGES

	CONCEIVE	DESIGN	IMPLEMENT	OPERATE
1. Polymeric industry	X			
2. Polymers and properties	X	X		
3. Design for injection	X	X		
4. Materials selection	X	X		
4. Snap fit design		X		
5. Pressure fit design		X		
6. Screw joints design		X		
7. Polymeric hinges designs		X		
8. Mold design: Basics			X	
9. Mold design:			X	X
10. Mechanical simulations		X	X	X
11. Injection simulations		X	X	X
12. Polymeric prototypes			X	X
13. Advanced applications			X	
14. Smart polymers				X

IMPLEMENTATION SCHEME

Basic design → *Detailed engineering*

Figure 3. Creativity promotion canvas for the "Implement" stage: Application to course on "Design and manufacturing with polymers".

<table>
<tr><td rowspan="2">OPERATE</td><td>Course: Design and manufacturing with polymers</td><td>Degree: Master's Degree in Industrial Engineering</td></tr>
<tr><td>Academic year: 2nd (Mechanical Specialization, Master's level)</td><td>Professors: Andrés Díaz Lantada, Juan de Juanes Márquez</td></tr>
<tr><td colspan="2">KEY PROCESSES FOR THE CDIO PROJECTS
- GROUP FORMATION: Proposal to arrange teams by personal decision of students.

- PROMOTION OF TEAMWORK: Providing a complex project, so that all students must be involved for a successful final result in just a single semester.

- CONTROL AND MENTORING: Intermediate and final presentations. Scheduled meetings.

- PROBLEM AND CONFLICT SOLVING: Conciliation meetings, teambuilding activities.

- COORDINATION OF PROFESSORS: Initial, intermediate and final meetings.</td><td rowspan="2">COURSE ASSESSMENT
- Measures to promote individual assessment: Weekly / monthly deliverables focused on analyzing real polymeric components and injection molding molds.

- Measures to promote positive interdependence: Providing a complex project, so that all students must be involved for a successful final result. Possible "face-to-face" challenges for teams with similar products.

- Final mark (%team & %individual): 70% for teamwork and 30% for individual deliverables

- CDIO projects assessment:
- - Process: Adequate following of planned process and activities for the different stages.
- - Results: Based on final design quality(and related prototypes).
- - Teamwork: Final dedication survey (hours and credits).
- - Communication: Based on oral presentations and written deliverables.
- - Creativity: Number of provided solutions and their related viability.
- - Other aspects: Proactivity, participation in class, relationship with other courses.

- Tools and resources for measuring satisfaction:
- - Of students: Continuous observation, periodic conversations, final results of the CDIO projects, surveys (both official and ad hoc).

- - Of professors: Final survey, conversations with colleagues, debates in congresses (i.e. CDIO International Conferences), acceptance of papers in journals.</td></tr>
<tr><td colspan="2">EVALUATION OF REQUIRED ECONOMICAL RESOURCES
(TOTAL €/YEAR): 2.000€ for CAD-CAE-CAM software, 200€/prototype
- FUNDING SOURCES: Enterprises that propose challenges or topics for the development projects, annual support by our department and teaching units, sponsorship of UPM's Product Development Laboratory.

- SUSTAINABILITY PLAN: Annual maintenance of CAD-CAE-CAM software licenses, materials and machines for prototyping, maintenance of computers and equipments, acquisition of standardized components, establishment of agreements with the industrial sector for sponsoring the developments and projects, compromise of Rectorate with CDIO experiences, funding provided by educational innovation calls, among other options.</td></tr>
</table>

Figure 4. Creativity promotion canvas for the "Operate" stage: Application to course on "Design and manufacturing with polymers".

CDIO CANVASES APPLIED IN A WORKSHOP FOR SPREADING THE CDIO MODEL

Once the CDIO canvases of Figures 1-4 were conceived and proven useful for summarizing the key aspects of CDIO courses and related CDIO projects, as illustrated before with the example of the "Design and manufacturing with polymers" course, they were further applied to mentoring colleagues with the CDIO of new CDIO experiences. To cite an example of how the CDIO model can be spread with the support of these creativity promotion tools, we summarize here the results from a workshop organized in 2019 in a Spanish university, with the objective of explaining the fundamentals of the CDIO model and of mentoring a group of interested colleagues, along the planning of new CDIO experiences and courses. The workshop lasted for two days (10 hours) and counted with the participation of 30 colleagues from different engineering disciplines. Empty CDIO canvases, to be filled in during the workshop, were provided at the beginning of the workshop sessions.

The following presentations (1 hour each) were given during such workshop:
- Introduction to the International CDIO Initiative and to the CDIO model.
- Two case studies linked to the creation and teaching of CDIO courses.
- Assessment of courses employing active learning methodologies.
- Management of a set of CDIO courses: Common problems & operative advices.

The following hands-on activities and debates were also carried out:
- Guided application of the "Conceive – Design – Implement – Operate" canvases to different potential new courses. Around 45 minutes were devoted for interacting with each canvas
- Discussions linked to main challenges and common solutions for the different stages of project-based learning courses. One-hour closing debates, one per day, helped to promote creativity along the workshop.

During the workshop, interesting ideas for creating new courses or reformulating ongoing ones, so as to follow the CDIO model and to promote active learning, were put forward by participants with the support of the provided tools and as a result of guided discussions. The most interesting courses and the related CDIO projects, which may help to involve students in the active application of the knowledge and skills acquired are listed in Table 2. Direct inspection of Table 2 helps to understand the multidisciplinary nature of the CDIO model and its valid application to almost all engineering disciplines. If the adequate driving questions are asked and if mentoring from colleagues throughout the CDIO community is promoted the model can further spread and reach many more universities and countries in a sustainable way.

Table 2. Summary of CDIO courses and related projects, proposed after an introductory workshop to CDIO, in which the developed canvases were employed.

Engineering course or area	Potential topic for CDIO projects
Electronics	Development of a control for a deposit
Electronics	PCB for analogic digital converter
Informatics	Design of websites
Theory of machines and mechanisms	Development of positioning mechanisms
Biomechanics	Devices for improving mobility
Materials Science and Engineering	Design of appliances using composites
Electricity	Project of a remote sustainable installation
Mechanical systems	Development of a laser dartboard
Theory of vehicles	Design of a testing bench for vehicles
Transport methods	Development of a transporting chain

CONCLUSIONS

CDIO has already transformed engineering education but its impact can be even larger if the model is further spread in a systematic way, so that additional countries, universities and engineering programmes may use CDIO as backbone for their scientific-technical higher education systems. Based on experiences by our team, a set of straightforward creativity promotion tools for the conception, design, implementation and operation of project-based teaching-learning experiences following the CDIO model has been developed. These tools take the form of "CDIO canvases", with which professors can interact, for answering driving questions and for considering main challenges, linked to the creation of innovative CDIO teaching-learning experiences.

This study has presented the CDIO canvases, as tools for spreading CDIO, illustrated their use by summarizing the most relevant aspects of a successful CDIO-PBL course and highlighted their potential for rapidly ideating new CDIO initiatives by presenting the results of an introductory workshop to the CDIO methodology performed with colleagues from several engineering disciplines. We expect that these tools may support creativity in education, as other canvases have proven useful for innovating in business and for start-up creation.

Finally, we would like to highlight that, in order to train colleagues with the use of these creativity promotion canvases, apart from presenting and explaining their use in current study, a related workshop for the CDIO of CDIO courses has been proposed by our team for the 16th International CDIO Conference in Thailand (2020). In such workshop, we expect colleagues to work in reduced groups for generating, analyzing and discussing ideas for innovative CDIO experiences. We hope that it may contribute to the systematic promotion of CDIO model's spreading.

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BIOGRAPHICAL INFORMATION

Andrés Díaz Lantada is Professor in the Department of Mechanical Engineering at ETSI Industriales – UPM. His research activities are aimed at the development of biodevices using modern design, modeling and manufacturing technologies and he incorporates these results to subjects linked to product development. He is Editorial Board Member of the International Journal of Engineering Education and CDIO contact at UPM. He has received the "TU Madrid Young Researcher Award" and the "TU Madrid Teaching Innovation Award" in 2014 and the "Medal of the Spanish Academy of Engineering to Young Researchers" in 2015.

Enrique Chacón Tanarro is Professor in the Department of Mechanical Engineering at ETSII – TU Madrid. His research activities are linked to several fields of Mechanical Engineering, including most areas of tribology and contact phenomena, machine performance assessment and systematic product development applied to energy engineering. He incorporates research results to subjects on "Machine Design", "Tribology", and "Engineering Design", and participates in several public- and private-funded research projects. He has recently been awarded the UPM Extraordinary Prize for his PhD on elasto-hydrodynamic lubrication.

Juan Manuel Muñoz Guijosa is Professor in the Department of Mechanical Engineering at ETSII – TU Madrid. His research activities are linked to several fields of Mechanical Engineering. After his PhD he was visiting researcher at MIT and worked some year for Bosch GmbH linked to the automotive industry. Since his reincorporation to TU Madrid he has been linked to subjects on "Mechanism and Machine Theory", "Vibrations Theory", "Engineering Design", among others, and participated in several research projects. More recently he has been visiting research professor at the TU of Tokio and at Drexel University.

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