# A CDIO APPROACH TO CURRICULUM DESIGN OF FIVE ENGINEERING PROGRAMS AT UCSC

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## ABSTRACT

This paper describes the process followed by the UCSC School of Engineering in order to redesign its five engineering programs using a CDIO-based approach. The redesigned programs were the Computer Science, Industrial Engineering, Civil Engineering, Logistics Engineering and Aquacultural Biotechnology Engineering programs. First, we present the motivations behind this work, namely, the desire to update the curricula so as to incorporate novel teaching and learning methodologies, and to improve our performance indicators. Next, we explain the UCSC ethos, its pedagogical model and the CDIO approach that together frame our curriculum design process. Then, the different stages of this process are presented and described at length. We then present several results from the Conceive and Design phases of the CDIO approach. These results also include reports from pilot Active Learning experiences and Service Learning experiences. Our curriculum design process started in 2008, and to date we have completed the Conceive and Design phases of the CDIO approach, with the Implementation phase starting this year. This has been a slow and laborious, but ultimately very rewarding, process. The main working team members had no previous experience with curriculum design, nor were they familiarized with currently engineering education trends. A Chilean MECESUP government grant allowed team members to visit leading innovative engineering schools, and also financed workshops for local faculty by well-known international experts. Our experiences to date and the growing involvement of early adopters and other faculty members show promise, and lead us to hope for a sea change in institutional mores by instilling the culture of continuous improvement in the educational process.

## KEYWORDS

Curriculum design; CDIO syllabus, benchmark, mapping CDIO skills

## INTRODUCTION

Over the last decades, there has been an increasing awareness that professionals coming out of engineering schools are not meeting all current industry needs. This observation is not related to the graduates' engineering knowledge but rather to certain lacking personal, interpersonal skills and attitudes. This issue has become common knowledge and has been revealed in many studies conducted in several countries, all of them reaching the same conclusions.

Most engineering programs in Chile present, in varying degrees, one or more of the following problems: inflexible curricula overly constrained with excessive courses and requirements, courses overloaded with contents, lack of flexibility within programs and also across different programs and universities, and a lack of intermediate exit degrees. Additionally, the School of Engineering of the Universidad Católica de la Santísima Concepción (UCSC) has identified other problems such as serious deficiencies in first-year student skills, low student retention rates, high course failure rates, and excessively long effective program durations.

The UCSC School of Engineering is committed to improving its current offerings. After an extensive exploration process, they decided to redesign its five engineering (Computer Science, Industrial Engineering, Civil Engineering, Logistics Engineering and Aquacultural Biotechnology Engineering) programs using a CDIO-based approach.

***Why a complete curriculum design and not just a specific innovation within the curriculum?***

We believe that, by not having a complete curriculum based on a CDIO approach, any specific initiatives that are carried out within the curriculum can sometimes get diluted during the student's learning process. This can be illustrated by picturing a very motivated student doing hands-on learning and who, after the bell rings, must attend his next class which is taught in a traditional way. During the first hour we're having him think for himself in order to learn, and in the next hour, we expect him to go back to a passive learning state.

Our first learning experience was realizing that the curriculum design process was by itself also an engineering process. Therefore, it can also be thought of as having all 4 parts of the CDIO approach (Conceive-Design-Implement-Operate). This work considers the conception and design of the new curriculum, as the implementation stage started March 2011.

As stated before, this has been a learning experience, and through this paper we will describe the whole process, as well as our main conclusions and recommendations.

## FRAMEWORK

The world has changed, it always has and it will continue to do so. This is a fact. Education hasn't always been able to keep up with this continuous transition, and engineering education is not the exception. Fortunately, this issue is already being addressed within many engineering schools worldwide, but they're faced with the difficulty that most engineering professors are experts in their fields, but not necessarily in education. Therefore, this new engineering education movement has taken them out of their comfort zone and into a new and unexplored field.

Refocusing education away from the traditional passive approach towards one more centered on the students and their skills and capabilities and less on knowledge, is a world movement that affects the entire education process (K-12 and higher education). There are several theories, movements, approaches, declarations and agreements among stakeholders and even countries (Tuning Latin America, the Declaration of Bologna, the CDIO initiative, among many others). In spite of the differences among them, they all focus on the same fundamentals: more skills and less knowledge, flexibility, a focus on learning outcomes, integral development, etc.

### *The UCSC Institutional Pedagogical Model*

The Universidad Católica de la Santísima Concepción is a private catholic university which brands its students with its hallmark through its institutional pedagogical model. The UCSC pedagogical model is a human-centered model based on four cornerstones, as shown in Figure 1. All new study plans and curricula must conform to this pedagogical model. This model was established in 2009, after our curriculum design process had already started. We now present the pedagogical model and indicate its correspondence to the CDIO standards, as presented in [2].

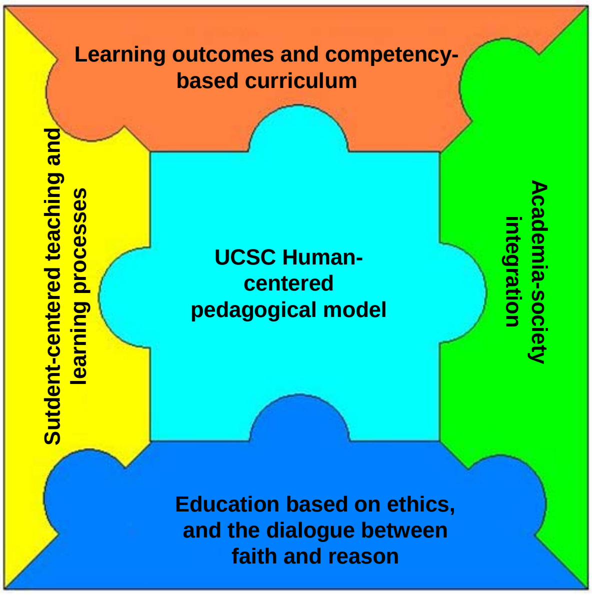


Figure 1: UCSC institutional pedagogical model

The first cornerstone is a learning-outcomes and competency-based curriculum, corresponding to CDIO Standards 2 and 3. It comprises recognizable and measurable competency-based program outcomes, intermediate program exits, flexible career paths, and evaluation by learning outcomes and competencies (CDIO Standard 11).

The second cornerstone is a student-centered teaching and learning process (CDIO Standard 8). It comprises faculty pedagogical and disciplinary development (CDIO Standards 9 and 10), progressive learning autorregulation, and teaching and learning resources availability (CDIO Standard 6)

The third cornerstone is education based on ethics, and the dialogue between faith and reason. It comprises recognizing truth as the convergence point between faith and reason, ethics education, and anthropological formation across the curriculum.

The last cornerstone is the integration of academia and society. It comprises generating meaningful links between student and society (CDIO Standards 4, 5 and 7), and also ensuring program outcome relevance to industry and society.

### *The CDIO Approach*

We embraced the CDIO initiative as our guiding framework because it proposes a student-centered curriculum, created for and by engineers in collaboration with education experts, that captures the essence of engineering itself, by stressing the fundamental domains of Conceiving, Designing, Implementing and Operating real-world systems and products. It is not only a methodological approach but also a network of associated institutions that collaborate by sharing their know-how and experiences in pedagogical innovations, to help improve engineering education. It has been applied successfully in many engineering program. Moreover, many of its available resources are written in a way that any engineering professor can understand. This is of great importance because of the fact that any curriculum change process has to be carried out within the engineering schools and by the faculty members themselves.

The CDIO approach addresses two main questions:

> "What is the full set of knowledge, skills, and attitudes that engineering students should possess as they leave the university, and at what level of proficiency?"
> "How can we do better ensuring that students learn these skills?"

To these two questions we add a third one: "How do we do this and where do we start?"

To answer the first question, the CDIO Initiative has developed a detailed and comprehensive list of knowledge, skills and attitudes that students should learn and be able to do at the end of their engineering studies. These learning outcomes are codified in the CDIO Syllabus. This syllabus can be successfully compared with other accreditation criteria, such as those used by Chilean higher education accreditation agencies. Moreover, the CDIO syllabus contains more levels of detail. Therefore, when facing the task of defining learning outcomes for an engineering program, it is wise to use the CDIO syllabus and to validate it with the local stakeholders, instead of starting from scratch.

The answers to the second question are contained within the 12 CDIO Standards, which could also be seen as the backbone of any engineering curriculum. They address issues going from the basic principle that engineers conceive-design-implement-operate products and processes, up to topics such as curriculum development, design-implement experiences and workspaces, methods of teaching and learning, assessment and evaluation. In regard to curriculum development, these standards state the need for a curriculum that integrates personal, interpersonal and engineering skills.

Among the teaching and learning methods, active learning is of particular interest to us. It changes the focus from the teacher towards the students, engaging them directly in their learning process, by the means of having them think and do experiential activities (by themselves or in groups), that will help them learn in a more active and effective way, as opposed to the traditional passive state of just receiving information. Therefore, active learning is a constructivist way of learning new knowledge, but not only that, since as a "side effect" or "spin off effect", it also helps develop other crucial skills and attitudes that are required in an engineer, such as learning to learn, teamwork and interpersonal skills and attitudes. There are many active learning methodologies and techniques that can be suitable for engineering programs but we will emphasize problem-based learning, inquiry-based learning, project-based learning and service-learning.

The third question will be answered throughout this paper, mainly by the exposition of our curriculum design process, for which we adopted the CDIO standards, as well as other curriculum design principles and techniques obtained from literature and experts.

## THE CURRICULUM DESIGN PROCESS

The main process used for conceiving and designing the new engineering programs is summarized in Figure 2.

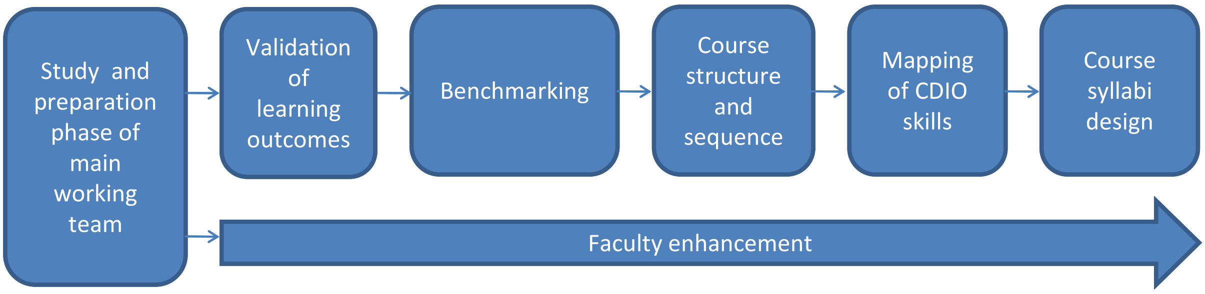


Figure 2. Curriculum design process

The organization used to carry out this process consisted of a main working team composed of six faculty members, two from the Computer Science program, and one from each one of the other four programs. This team was the driving force of the process, and each member was charged with acting as the nexus with faculty of their own department.

***Study phase and preparation of main working team***

The initial study and preparation phase was carried out by the main working team, which had the responsibility of conceiving the process and setting out a road map. This first stage, and the team itself, were crucial and became the foundation of the whole process.

The initial steps taken were to diagnose the current situation according to the latest developments in engineering education locally and throughout the world, and also to take an inside look of the situation at UCSC and the local industry. The results of this diagnosis weren't any different from those obtained by other studies conducted in Chile and worldwide, whose main conclusions were already stated at the beginning of this paper. The only major difference detected was regarding the pre-existing skill set of first-year engineering students at UCSC. Five tests were applied to first-year engineering students, in order to determine their entry conditions regarding their social skills, self-concept, their skills using information and communication technologies, mathematic skills and basic language skills. Each test is briefly described below:

*Social skills*: This test evaluates skills in terms of interpersonal relationships, assessing their behavior in different situations.
*Self-concept*: This test evaluates the concept that each student has of him or herself, considering five dimensions: social, academic/professional, emotional, family and physical.
*Information and communication technologies skills*: This test assesses the students' skills at using a computer. Some self-contest test results are presented further ahead.
*Mathematics*: This test evaluates basic algebra and calculus skills to establish a baseline.
*Basic language skills*: This test assesses reading comprehension and production of a text of no more than 200 words on a given topic, assessing the organization of ideas, writing, spelling and quality of writing.

An important outcome of this phase was deciding upon a specific model or approach to be applied to the curriculum design process. To this purpose, visiting foreign educational institutions and seeing other innovative experiences first-hand was truly helpful and a real eye-opening experience. It was during this exploration phase that the CDIO approach was selected as our main model.

Another important input considered in this phase was the experience of two other Chilean engineering schools, those of the Universidad de Chile and the Pontificia Universidad Católica de Chile. They used the CDIO syllabus for their curriculum renovation process, and validated it with local stakeholders.

Another fundamental decision taken during this phase was to rely on expert assistance. In spite of all available written and online resources, it is fundamental to have the help of someone that can lead you through the process, especially if the main working team doesn't have any previous curriculum design experience. In our experience, the expert selection is a crucial decision, as that person must have experience working with both engineering curriculums as well as with engineering faculty. In our case, we were fortunate enough to work with Prof. Doris Brodeur from M.I.T., who is not only part of the CDIO initiative, but also has a vast experience in curriculum.

This curriculum design process was financed through a MECESUP grant (USC06010), which are government funds aimed at improving the quality of higher education. This specific project had as its goal the formulation of a plan for a curriculum reform process of the engineering programs at UCSC, emphasizing competency development, curricular flexibility and continuous education.

### *Faculty Enhancement*

Faculty enhancement is a long and laborious process, requiring extensive support and commitment from the host institutions, and much dedication and personal effort from the team participants. To this purpose, the international CDIO network has proved itself priceless, as it has allowed us to participate in international workshops, share experiences and novel teaching ideas with enthusiastic engineering educators from all over the world.

Starting in mid 2006, the School of Engineering created its main working team, which was tasked with leading the effort to renovate the curriculum of 5 programs, with the stated goal of applying for the aforementioned government MECESUP grants. To this end, team members attended several national-level workshops, conferences and seminars on educational reforms in higher education. In particular, the team got familiarized with the Tuning Latin America project, the Declaration of Bologna, and other educational initiatives.

After applying for and receiving a MECESUP grant for the curriculum renovation at the School of Engineering, the main working team focused specifically on curricular renovation experiences in Engineering Education. Thus, they got acquainted with the CDIO Initiative through the experience of the Universidad Católica de Chile and the Universidad de Chile. This framework appeared to be uniquely suitable for the process at hand.

Faculty enhancement was performed as follows: main working team members visited several international institutions that have implemented innovations in engineering education to study them in situ. These visits led in turn to contacts with experts in several areas, some of which were invited to give workshops at UCSC and help guide the curriculum design process. At the same time, team members also led workshops for other faculty members, so as to motivate and engage them in the curriculum reform.

*Visits*

In 2008, team members visited the Franklin W. Olin College of Engineering and got in touch with Doris Brodeur. Also, they attended the International and Regional CDIO Meeting at Arizona, which in turn led to contacts with several other CDIO members and LASPAU. In particular, we got in touch about other Latin-American engineering schools that are implementing curriculum reform projects using the CDIO approach, such as UNITEC – Honduras and the Universidad Javeriana, in Colombia. This was a very productive and motivational meeting, which led us to attend the 2009 CDIO Region of the Americas Workshop at Boulder, Colorado. At the same time, LASPAU was instrumental in arranging visits to Harvard University, where we learnt about effective class management and how their teaching and learning centers support faculty improvement and innovation; to the Massachusetts Institute of Technology, where we visited the Dept. of Aeronautics and Astronautics to learn about their experiences with the CDIO Initiative, and also heard about M.I.T.'s Writing across the Curriculum program; to Brown University, where we visited the Sheridan Center for Teaching and Learning; and finally to Olin College of Engineering, where team members got knowledge of their hands-on learning and project-based programs, with their emphasis on social responsibility and innovation.

In October of 2009, team members visited Sherbrooke University, Canada to learn about competence-based curricula, project-based learning and co-operative education models. Later, at the École Polytechnique de Montréal they became familiarized with the curricular reform process based on the CDIO approach followed at the Mechanical Engineering Dept., and visited the Bureau D'Appui Pedagogique to learn about the extensive pedagogical support available to both full-time and part-time faculty at this center. At the Massachusetts Institute of Technology, team members visited the Teaching and Learning Laboratory and heard about their experiences with the application of active-learning methodologies to their first-year physics courses, and also how their engineering leadership programs are preparing future leaders in innovation and invention. The team's visit to Northeastern University was very insightful, thanks to their vast experience with co-operative learning, service learning and project-based learning, as well as their relationship model with industry and other organizations. At Bentley University and at the Massachusetts College of Pharmacy and Health Sciences, team members learnt even more about service learning and how to build successful relationships with community organizations. Finally, visiting the Worcester Polytechnic Institute was a great introduction to project-based learning and their experiences with projects that take students abroad.

In 2010 team members visited the University of New England in Armidale, Australia, to learn about the design and development of measures and instruments for curriculum assessment.

*Workshops*

In mid-2009, a workshop on how to benchmark core engineering fundamentals using a specialized tool based on an Excel spreadsheet was held and attended by all full-time participating faculty members at UCSC.

Doris Brodeur visited UCSC in August of 2009 for two weeks, during which she led a workshop on designing an Outcomes-Based Curriculum, and a workshop on The Course Syllabus: Planning Student-Centered Courses. These workshops were attended by faculty of all engineering programs, many of whom became early-adopters of the proposed reforms.

Susan Vernon-Gerstenfeld from the Worcester Polytechnic Institute visited UCSC in October of 2010, where she led a workshop on Applying Project-Based Learning to Undergraduate Courses, and a workshop on Applying Project-Based Learning to a First-Year Undergraduate Course. These workshops were open to all engineering faculty.

Also, in 2010, the UCSC created the Centro de Innovación y Desarrollo Docente (CIDD), a teaching and learning center to assist full-time and part-time faculty in improving their teaching skills and to support education innovations. To this purpose, they certify faculty members in: learning-outcomes based course design, active-learning methodologies, learning-outcomes assessment, and using information technology tools in higher education.

With the creation of CIDD, the School of Engineering handed over the responsibility of assisting faculty members who wish to improve their teaching skills and incorporate novel educational ideas to CIDD. At the same time, the CIDD has given first priority to those university programs that are implementing curriculum reforms.

This is only the first step. Faculty enhancement is a slow, deliberate process that requires resources, time, effort and dedication from the faculty, but we are confident that the creation of the center marks a milestone in the road to continuous teaching skills improvement at UCSC.

***Validation of Learning Outcomes***

Learning outcomes validation was done using the learning outcomes and skills list proposed by Universidad de Chile and Pontificia Universidad Católica de Chile in [1], which is an already validated version of the original CDIO syllabus, slightly modified for the Chilean context. The validation process was done through surveys, interviews and focus groups with the main stakeholders (students, alumni, employers and faculty).

The same survey designed by [1] was used to validate learning outcomes, as to allow future comparisons. Faculty, employers and alumni of each of the five engineering programs answered the survey via a web application. Survey subjects evaluated the importance of each skill using the scale shown in Table 1.

Table 1. Evaluation Scale

| **Level** | | |
|---|---|---|
| 0 | | *It's not necessary to have obtained any proficiency level of the skill.* |
| 1 | To know | Have been exposed to the skill |
| 2 | Participate and Contribute | Know and discriminate situations or activities that require the skill |
| 3 | Understand and Explain | The capacity of being able to pass the skill to others and train them, |
| 4 | Apply | The capacity of being able to put in practice or implement the knowledge or skill in the right situation |
| 5 | Innovate | The capacity to manage and apply perfectly the skill in order to be able to innovate, lead and create new knowledge in the field |

After the surveys, interviews and focus groups were carried out in the cities of Concepción, Temuco and Santiago, to faculty, employers and alumni. Some key headhunters were also interviewed.

***Benchmarking***

The benchmarking stage had 2 main parts. The first part involved benchmarking the CDIO skills (levels 2, 3 and 4 of the syllabus), and teaching methods and the second part benchmarked core engineering fundamentals (level 1 of the syllabus). Normally, this last part is not necessary for US or Canadian engineering programs. However, courses in Chilean engineering programs are usually overloaded with technical knowledge. Thus, in our case benchmarking allows us to identify the "fat" in our courses.

When benchmarking the CDIO skills, faculty had to determine which specific skills, up to the second level of detail of the CDIO syllabus, were addressed in their course. Also, they had to specify the manner of addressing each one of them as one of the following:

*Introduce*: The skill is only mentioned and is not assessed.

*Teach*: Significant time is spent on teaching the skill (theory, practice and/or application), and it is assessed.

*Use*: The skill is used, that is, the student is expected to have learned this skill previously.

A slightly different approach was used to benchmark the core engineering fundamentals. For every specific course content, faculty had to specify the level at which it was taught: theory, practice or application; what specific technical knowledge did a student need to know, and the time required inside and outside the classroom.

To this purpose, we designed a tool using a Microsoft Excel spreadsheet, which turned out to be very useful for the faculty members that were consulted, as it didn't require any assistance, and also made data processing much easier.

*Benchmark spreadsheet design*

Two different spreadsheets were designed for the benchmarking process. For the first part, skills up to the second level of the CDIO syllabus (x.y), were listed in the spreadsheet. The third level of detail (x.y.z) was displayed afterwards within a frame, as shown in Figure 3.

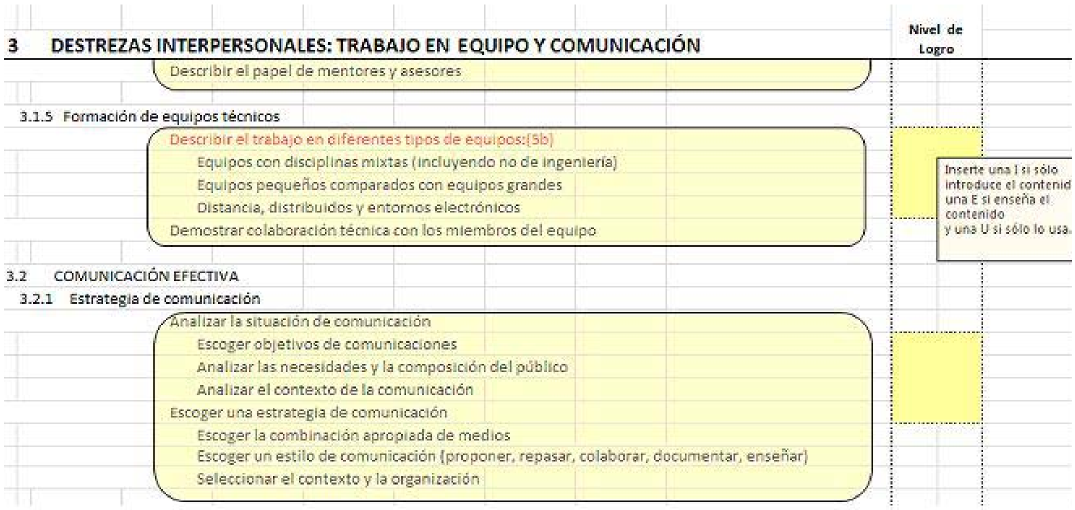


Figure 3: Personal, interpersonal and engineering skills template

When filling out this template, each faculty simply had to type in the yellow square one of the 3 options for addressing a specific skill: **I**: introduce; **T**: teach; **U**: use. If the skill was not addressed, they could simply leave it blank. The spreadsheet came with clear instructions, definitions and an example of how to fill out the template.

The spreadsheet design for the second part of the benchmarking process was slightly different. In this case, all courses were listed in the spreadsheet, along with their contents. Each course and content had a specific code, as shown in Figure 4.

Figure 4 shows the technical knowledge template for General Chemistry (Química General). The course code is 1.1.3, and it includes 11 contents or technical knowledge skills (codes 1.1.3.1 to 1.1.3.11). When filling out the template, professors fill out the columns on the right hand, which consider three aspects that were being benchmarked:

How that specific content was being taught (Theory, practice or by application).

Number of hours that a student should dedicate to the content (within and outside of the classroom). Faculty must also indicate whether the amount of hours considered were enough.

Which specific content (or technical knowledge skill) should the student already know in order to learn the one specified in the course being benchmarked, and at what level (theory, practice or application). Codes for other contents could be found easily within the spreadsheet.

**IDENTIFICACIÓN GENERAL CURSO**

| | |
|---|---|
| Carrera: | |
| Código Asignatura: | |
| Nombre Asignatura | |

| | | | | | Enseña | | | Horas semestrales | | | contenido 1 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | se enseña a nivel | | | | | | | se necesita que se enseñe | | |
| 1 | | CONOCIMIENTO TÉCNICO Y RAZONAMIENTO | | | | | | | | | | | | |
| 1.1 | | CONOCIMIENTO DE CIENCIAS BÁSICAS | | | T | P | A | presenciales | no presenciales | ¿Es suficiente? (S:si/N:no) | código | T | P | A |
| | | | 1.1.2.3 | Límite de funciones reales. | | | | | | | | | | |
| | | | 1.1.2.4 | Continuidad. | | | | | | | | | | |
| | | | 1.1.2.5 | La derivada | | | | | | | | | | |
| | | | 1.1.2.6 | Aplicaciones de la Derivada | | | | | | | | | | |
| | | | 1.1.2.7 | $R^2$ y el plano real cartesiano. | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | 1.1.3 | QUIMICA GENERAL | 1.1.3.1 | Estructura atómica y clasificación periód | | | | | | | | | | |
| | | | 1.1.3.2 | Enlaces químicos | | | | | | | | | | |
| | | | 1.1.3.3 | Nomenclatura básica | | | | | | | | | | |
| | | | 1.1.3.4 | Leyes gravimétricas | | | | | | | | | | |
| | | | 1.1.3.5 | Ecuación química | | | | | | | | | | |
| | | | 1.1.3.6 | Estado gaseos | | | | | | | | | | |
| | | | 1.1.3.7 | Termoquímica | | | | | | | | | | |
| | | | 1.1.3.8 | Mezclas | | | | | | | | | | |
| | | | 1.1.3.9 | Cinética y equilibrio químico | | | | | | | | | | |
| | | | 1.1.3.10 | Equilibrio iónico | | | | | | | | | | |
| | | | 1.1.3.11 | Oxido reducción y electroquímica | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | 1.1.4 | ALGEBRA II | 1.1.4.1 | Vectores en $R^2$ y $R^3$. | | | | | | | | | | |

Figure 4. Technical knowledge template

This information was processed in order to build a matrix that would allow different analyses. Hence, it was possible to establish which contents were required by other courses,helped us identify redundant content throughout the course programs, as well as establish relationships between the courses.

***Course structure and sequence***

The structuring and sequencing of the courses was carried out in different ways by each of the different engineering programs. However, they all considered as their input the output of the benchmarking process, which allowed them to rank all topics in order of importance.

The main working team developed a series of recommendations to guide the course structure and sequence, such as the number of courses per semester, number of service-learning hours, internship requirements, etc. As mentioned before, the UCSC's own curricular framework and pedagogical model set constraints on course structure and sequence. The desire to meet Chilean national accreditation board requirements and suggestions also put pressure on this stage. In some cases, such as the Computer Science program, the Association for Computing Machinery's curricular proposals were taken into account.

There was at least one member of each engineering program in the main working team, who was tasked with organizing a curriculum committee for course structure and sequence. This committee included a representative sample of all the program's specialization areas. The committee's job was to reorganize the existing course grids to eliminate unnecessary course requirements, elide redundant contents, reduce and streamline critical course paths, among other tasks.

These new curricula incorporate significant changes in the first-year introductory courses for all five engineering programs undergoing curriculum reform. Traditionally, these courses met for one or two hours a week, which was clearly not enough time for students to become fully acquainted and motivated with their chosen professions. Our new curriculum design expands these courses to eight hours a week, so as to properly introduce students to their chosen fields of study, and also to familiarize them with the role of the engineer in today's society. Additionally, they must team up to plan and manage a simple project so as to exercise the CDIO basic competences (conceive-design-implement-operate). This course modification has been inspired by the University of Sherbrooke's first-year civil engineering courses [3]. These new courses also incorporate spanish-language teachers tasked with improving students' oral and written communication skills, specifically in technical reports, essays and oral presentations. Other communication skills courses were removed from the course grid and their learning outcomes are incorporated across the curriculum in a similar manner. These ideas, which are based upon the Writing across the Curricula program at MIT [4], present new challenges and opportunities for multidisciplinary and synergistic relationships between the schools of Engineering and Education.

At the same time, the UCSC has recently created the Centro de Acompañamiento del Estudiante (CEADE), a pedagogical center aimed at supporting the development of entering students' entry-level skills. This center has led workshops on improving study skills, autonomous learning and network building, which are held during the first five weeks of the introductory engineering courses.

**Mapping**

The activities previously mentioned lead to the mapping of the CDIO skills in the curriculum, which is one of the main cores of a CDIO-based curriculum. By mapping the CDIO skills within the curriculum we are taking responsibility for each one of them and making certain that students are exposed to a coherent curriculum. In other words, an integrated curriculum incorporates the personal, interpersonal and technical skills within the disciplinary courses, which traditionally address just disciplinary issues.

To this end, the curriculum committee for each program met during programmed working sessions with the grid of courses at hand. This committee was tasked with mapping each of the CDIO skills to one or more courses, in terms of being introducing, teaching or using the particular skill. For this task to be successful, constructive discussion is crucial and must be encouraged. Care must be taken to balance skills coverage across the courses. Also, it must be ensured that no skill is taught before it is introduced, nor used before it is taught. It is important to point out that the acquisition of any specific skill is a process that requires time, effort and training, so it's not something that you simply learn in a course. Therefore, each one of these skills should be taught in more than one course, and in each case the level of proficiency expected should differ.

Finally, it was also necessary to assert those particular skills that comprise UCSC's hallmark and make sure that they are included across the board.

***Course Syllabi***

Traditionally, our course programs have been written following a contents-based approach. An active learning approach requires course programs to be restated in terms of learning outcomes, and the syllabi helps ensure that students accomplish these learning outcomes. Initial work was done thanks to Prof. Doris Brodeur's workshops but later the CIDD took over the task of training faculty to use new institutional templates for course program and syllabi design. Additionally, the CIDD offers mandatory workshop for first-year engineering faculty on these subjects. These workshops will be soon extended to the rest of the faculty.

## RESULTS

The work presented in this paper is the description of a Conceive-and-Design process, therefore, there are still no implementation results to report. Nevertheless, some of the activities carried out through the process generated interesting results and data that are presented below.

### *Self-Concept Test Results*

As was previously stated, we applied five tests to first-year engineering students, in order to determine their entry conditions regarding certain skills. In this section we will give some results regarding the application of the self-concept test.

For this evaluation, we used the test presented in García y Musitu, which evaluates 5 basic dimensions: academic, social, emotional, family and physical [5].

From the results, it can be concluded that women had a higher self-concept in the academic, emotional and family dimensions, and a lower self-concept in the physical and social dimensions, when compared to men. There are no significant differences in the self-concept dimensions across engineering programs.

### *Validation of Learning Outcomes*

As previously explained, learning outcomes validation was done through surveys, interviews and focus groups with the main stakeholders (students, alumni, employers and faculty). In the following figures, we present some of the main results obtained from the surveys for the Industrial Engineering program. Figure 5 shows the personal and professional skills evaluations made by the stakeholders, while figure 6 shows the interpersonal skills evaluations. Figure 7 shows the engineering skills evaluations made by the stakeholders, while figure 8 shows the technical knowledge skills evaluations.

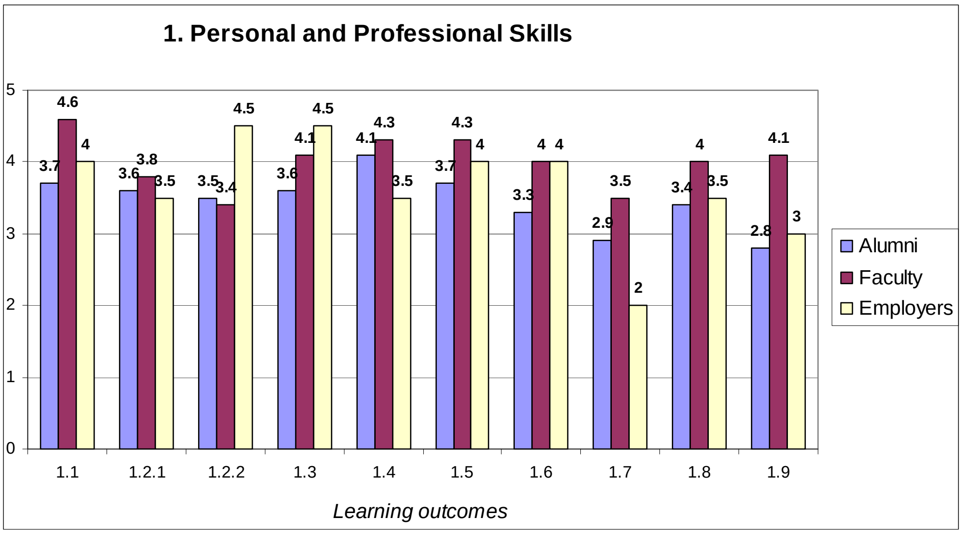


Figure 5: Personal and professional skills evaluation

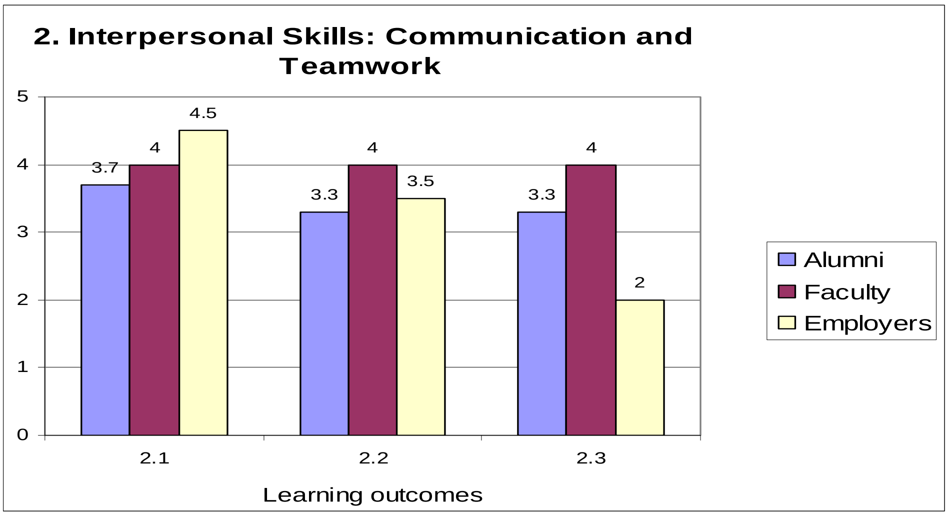


Figure 6: Interpersonal skills evaluation

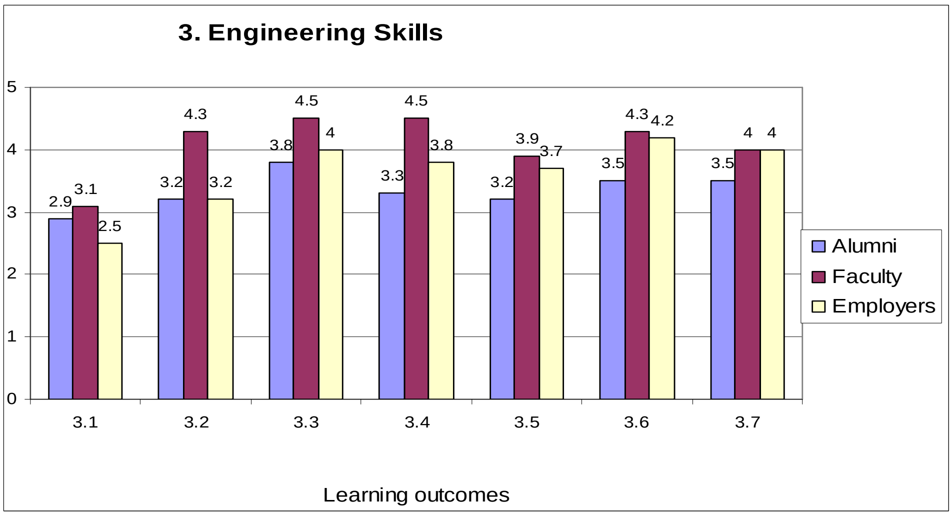


Figure 7: Engineering skills evaluation

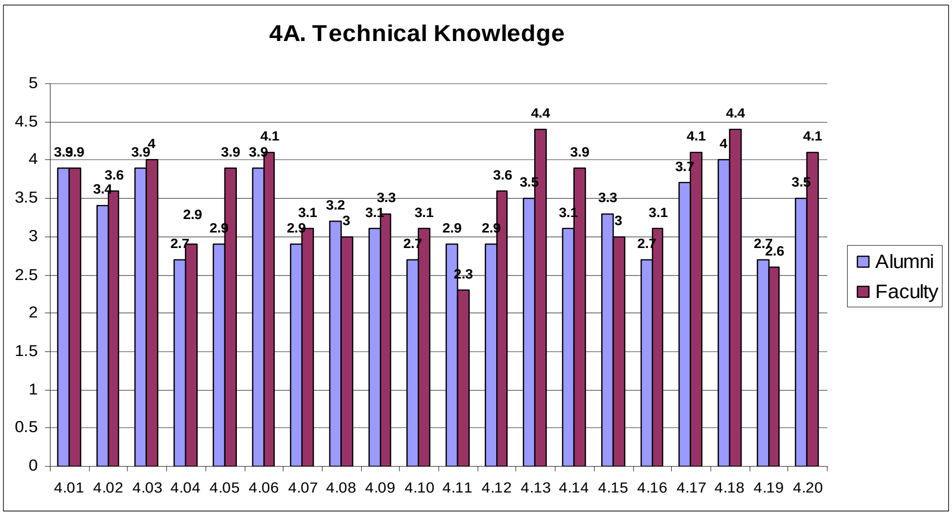


Figure 8: Technical knowledge skills evaluation

From analising the data, we observed a strong positive correlation among the answers given by the different stakeholders and also between the different engineering programs. The data shows that faculty consistently overestimates the importance of technical knowledge, when compared to the other stakeholders.

The importance of alumni opinion can be seen in that it has the most statistical significance, as their answers have the highest correlation with the final results of the validation process. Also, of all stakeholders, alumni are usually those more willing to participate in these activities.

***Benchmark results***

The technical knowledge benchmark yielded several useful insights: many courses had topics that are not required knowledge for any other course in the grid. We also encountered courses that do not add to the learning outcomes program. Finally, the benchmark helped uncover redundancies where some topics were covered in more than one course

The personal, professional and engineering skills (PPE) benchmark helped us see that, while some courses address a large amount of PPE skills, others don't address any PPE skills. Many PPE skills are used in more than one course, but are not specifically taught in any courses. In fact, PPE skills are concentrated in just a few courses of the grid.

***Innovative Pilot Experiences***

*Service Learning in Industrial Engineering*

During the second semester of 2010, the Industrial Engineering program created a new elective course for seniors called “intervention in disadvantaged areas”. In this occasion, the project was oriented toward helping neighbouring fishing villages which were damaged in the 2010 earthquake. As such, this course was also open to Marine Biology students. These students surveyed the marine resources management area to assess its post-tsunami status. At the same time, the Industrial Engineering students formulated and evaluated development projects to help these tsunami-ravaged fishing villages. Students worked with community leaders, fishermen, and family businesses to empower them to submit these projects to government grants at the regional and national levels. This work represented a significant savings for the community. Students showed great commitment and motivation, and all of them appreciated the opportunity to work in multidisciplinary teams on real-world problems in a socially responsible manner.

*Problem-Based Learning in Aquacultural Engineering*

The Aquacultural Engineering program incorporated problem-based learning in four courses. Students had to work autonomously, research relevant literature, design cultivation systems and periodically present their work. During these semester-long courses, students developed personal and professional skills such as responsibility, leadership, teamwork, critical thinking, creativity and resourcefulness. Students reported being highly motivated with these courses, many of them going beyond course requirements in their research projects. In some cases, their coursework led them to present their work in national-level conferences, with excellent results.

## CONCLUSIONS AND DISCUSSION

Simultaneously re-designing five engineering curriculums has been an overly ambitions, work-intensive, slow and ultimately very rewarding collaborative group effort. We have currently finished the course syllabi design stage for all first-year courses. We are now working on course syllabi for the rest of the curriculum, which, for some courses, is now an interdisciplinary effort, as they require input from several faculty members.

Embracing the CDIO inititiative was crucial in our curriculum design process, since it's a framework designed for engineering programs. Access to the CDIO network of associated institutions, as well as to the many resources available on the CDIO website, has been of paramount importance to our efforts, as they have shown us tried-and-true educational techniques and approaches and also how to adapt them to our current reality.

Curriculum design has at times been a tedious and slow process, full of challenges and obstacles, that has extended itself beyond the original frame time. At the same time, it has been a unique team effort, which has brought together engineering faculty from different areas without any previous experience in curriculum reform. In spite of this, they were able to get out of their comfort zone and into a new discipline in which they ended up becoming the early adopters among their peers.

It is worth mentioning that, concurrently with our curriculum reform efforts, the university defined its pedagogical model and curricular framework for all its programs, and created a teaching and learning center as well as a student support center. This university initiative obviously aids the educational process, but because of the moment at which they were created, it sometimes resulted in lack of coordination between our efforts and duplicity of work.

Faculty enhancement is without any doubt a crucial stage in this process, not only during the conceive and design phases, but also, and maybe even more importantly, during the implementation and operation phases. It is fundamental to instill within the institution the culture of continuous improvement. Faculty are not always willing to commit to these changes, therefore a clear institutional vision and the proper incentives from the authorities are needed.

The active learning pilot experiences proved to be a very effective way of achieving the technical learning outcomes, as well as the so-called soft skills heretofore found lacking in previous students. Also, they were shown to highly motivate students as they engaged them in their own learning process. Introducing real engineering problems and experiences in the classroom helps students understand the fundamentals and see the theory into practice.

In retrospect, even though the curriculum design process described presents many difficulties and challenges, the application of the CDIO approach has proven to be effective, synergistic and also a great hands-on learning experience

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