An Approach to the Implementation Process of CDIO

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An Approach to the Implementation Process of CDIO

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ABSTRACT

The implementation of integrated curricula following the CDIO recommendations may result in natural and straightforward processes for mature universities. Nevertheless, a CDIO-based curricular reform can result in an overwhelming and error-prone process when universities lack experience in the consolidation of curricula that naturally integrate disciplinary learning outcomes with engineering skills. In this paper we propose a general and replicable approach to the implementation and continual improvement of integrated curricula based on CDIO; and report on our experience and lessons learned during the redefinition of the curricula of the Telematics Engineering and Computing Systems Engineering programs at Universidad Icesi, in Colombia.

KEYWORDS

Integrated curricula, CDIO implementation, curricular reforms, assessment, engineering education

1. INTRODUCTION

CDIO recommendations have been borrowed from best practices applied in several renowned and mature engineering schools worldwide. Therefore, the implementation of CDIO in such universities may result in a natural and straightforward process. Nevertheless, most engineering faculties, particularly in Latin America, lack resources and experience in the consolidation of engineering education best practices, despite their quality and commitment to improving and innovating in their programs' curricula. For these institutions, the implementation and consolidation of engineering education best practices still constitute a work in progress. Despite the remarkable efforts of the CDIO community at documenting the syllabus and recommended best practices for the realization of integrated engineering curricula, and the several papers contributed by universities reporting on their CDIO implementation experiences, to the best of our knowledge the CDIO initiative still lacks of a guide for its implementation processes. These guidelines are highly required to help institutions answer frequent questions that arise at different stages of the process. The Faculty of Engineering of Universidad Icesi, Colombia has been working for about two years on a curricular reform and the implementation of CDIO for two of our undergraduate professional programs: Telematics Engineering and Computing Systems Engineering. In this paper we report on our experience and lessons learned during the redefinition of our curricula and implementation of CDIO, and describe the process that we have followed including success key factors, activities, roles, interactions among all actors, as well as supporting tools and forms. Our goal with this paper is to report on the experience that we have gained during the implementation of integrated curricula based on CDIO, and provide a set of guidelines that can be replicated and tailored by other institutions, in particular by Latin American universities.

This paper is organized as follows. Section 2 discusses the motivation behind this work. Section 3 presents an overview of our curricular reform implementation process. Section 4 describes the drivers that motivated our curricular reform project. Sections 5—8 present the details of (i) our curricular reform implementation process at the *macro*, *meso* and *micro* curricular levels, and (ii) our curricular evaluation and continual improvement process. Finally, Section 9 discusses lessons that we have learned throughout the process and Section 10 concludes the paper.

2. MOTIVATION OF THIS PAPER

The CDIO approach has been successfully applied to the design of integrated engineering curricula worldwide, and particularly in renowned universities of North America and Europe [6][8][9][11], where the CDIO community had its genesis. One of the first universities in implementing an integrated engineering curriculum based on the CDIO initiative was the Royal Institute of Technology (KTH) of Sweden, first for its Vehicle Engineering program and then for several others [6]. As in all the subsequent successful implementations of CDIO-based curricula, the implementation process for KTH had to be aligned with the requirements of key stakeholders, for example, accreditation frameworks, national guidelines, and the Swedish industry's expectations. Therefore, despite the general definition of the CDIO standards, curricular reform processes are influenced by cultural factors. This is not only because stakeholders are immersed in particular cultures, but also because there are always cultural factors affecting the definition and management of the process itself.

Two Chilean universities pioneered the application of CDIO in Latin America: Universidad de Chile (UCH) and Universidad Católica de Chile (UC) [7]. The curricular reform processes defined by these two universities were based on the process defined by KTH in Sweden, and are publically available as a single process in [7]. Besides studying the CDIO standards and several international experiences, we have studied the approach followed by UCH and UC looking for a process that provides guidelines for the definition of our own process. Nevertheless, we found that the description of the Chilean approach was too general to be replicated in other Latin American institutions, or presents the phases disconnectedly without making explicit (i) the information flows among them, (ii) the used forms or tools, and (iii) the actors with their responsibilities.

To the best of our knowledge, there are no other Latin American reports that provide detailed guidelines of a replicable process for the implementation of curricular reforms based on the CDIO recommendations. In particular, we found no publications that help faculty understand and address the challenges that they will face when implementing curricular reforms for the first time. For example, it took a long time for us to understand that one of the most important challenges of this process is the definition of traceability mechanisms to keep track of the evolution of learning outcomes along the curriculum. This is particularly important for Latin-American universities where many of the faculty members are sessional instructors or part-time professors, and active learning models demand the administration of several sections per course.

3. OVERVIEW OF THE PROPOSED APPROACH

The implementation process that we present in this paper comprises four main phases (cf. labels 1—4 in Fig. 1). The first phase, which corresponds to the macro-curricular level, focuses on the definition of the professional competencies and the selection of the subset of CDIO learning outcomes that we expect our students accomplish along the program. In general, the main incomes of this phase, the curricular reforms' drivers, are the surveys applied to the stakeholders (e.g., industry, alumni, accreditation boards, students and faculty members), the institutional educational project (PEI, for its acronym in Spanish), and the CDIO syllabus [3]. The outcome of this phase is the *curricular matrix,* which associates professional competencies and CDIO learning outcomes with the courses of the curriculum, including the levels of proficiency that must be achieved for each learning outcome at each course. The second phase, which corresponds to the meso-curricular level, concentrates on the definition of terminal learning objectives from the selected CDIO program learning outcomes, which in turn are associated with the professional competencies of the program. The result of this phase is the *course card,* which contains the terminal learning objectives, as well as teaching & learning (T&L) and assessment strategies at the course level. It is important to point out that the meso-curricular level may be an optional phase in the process (cf. dashed box in Fig. 1), depending on the level of coordination required for courses with several sections, university policies, or educational models. The third phase, which corresponds to the micro-curricular level, focuses on the design of both the course syllabuses and the assessment strategies. The outcomes of this phase are the course syllabuses, which include the learning and assessment strategies to be applied by the professors responsible of each course. Finally, the fourth phase, which corresponds to the curricular evaluation level, allows us to collect evidence about the performance of the students and the development of the courses along the term, to implement the assessment feedback loop from verification to the definition of strategies to ensure the continuous improvement and innovation of the curriculum. Figure 1 also lists the key roles, as well as tools and forms that we defined in our process.

4. CURRICULAR REFORM DRIVERS

Curricular reforms are often motivated by existing gaps between the requirements and expectations of key stakeholders and the curriculum delivered to students of a professional program. Key stakeholders can be classified in four groups: students, industry (including program alumni), university faculty, and society (including government and accreditation boards) [1]. We define *curricular reform drivers* as the evidence that demonstrate the need to modify a program curriculum to improve its quality, which can be characterized in terms of its compliance with the expectations of key stakeholders.

Figure 2 depicts the key stakeholders and corresponding drivers that motivated the curricular reforms of our Telematics Engineering and Computing Systems Engineering programs. Rounded boxes correspond to general categories of stakeholders applicable to any curricular reform [1]. Bold labels (e.g., **last year students**, **faculty**) are the actors that represent the key stakeholders in our process. Squared boxes represent the drivers that not only motivated the curricular reforms of our two programs, but also provide valuable information for the continual improvement of our curricula. Most drivers, except the ones obtained from **referents**, are derived from evaluations conducted by internal and external stakeholders. Actors belonging to *Students* and *University Faculty* correspond to internal stakeholders, whereas actors in the groups *Industry* and *Society* correspond to external stakeholders.

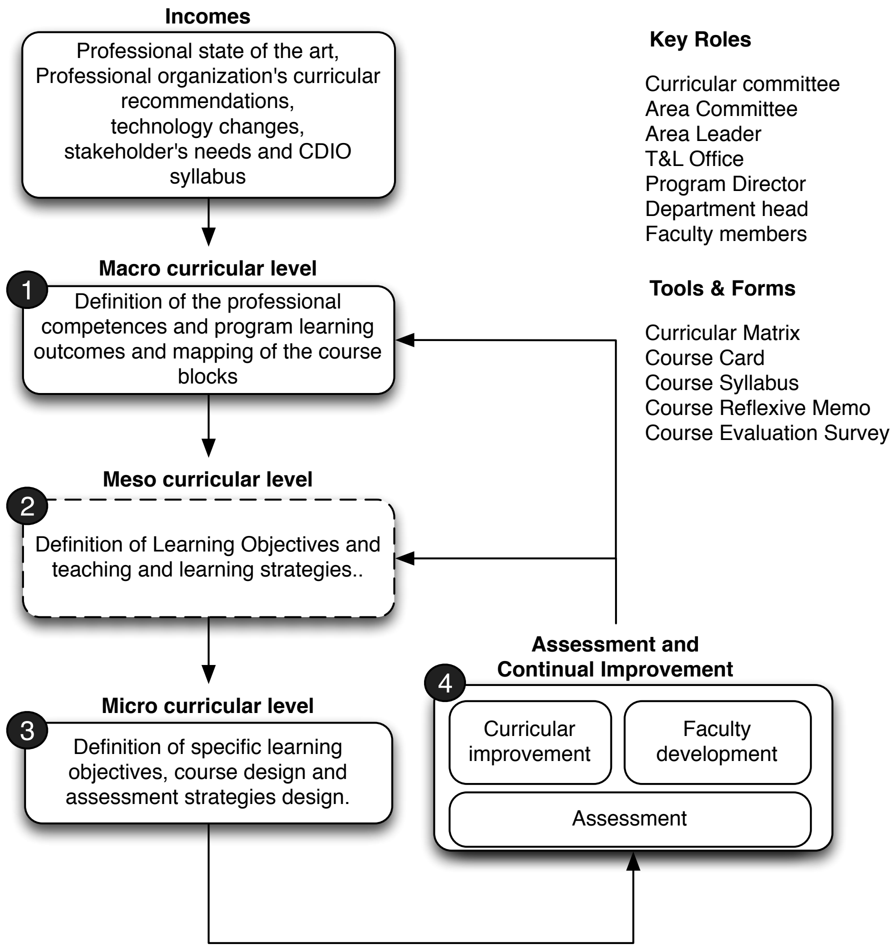

Figure 1 - Curricular reform general structure

Drivers associated with internal stakeholders: In the curricular reforms discussed in this article, last year students complete a survey that evaluates, among others, the most relevant aspects of the curricular program. In particular, this survey allows us to collect evidence on the satisfaction of students with respect to: (i) the disciplinary and engineering skills obtained along the program. Students judge this aspect based on their performance during their graduate internship program, which is usually completed in the last term of their career; (ii) the effectiveness of integration and capstone projects conducted along the curricula to strengthen their disciplinary and engineering skills; and (iii) the suitability of the T&L strategies applied by the university faculty. Besides the evidence gathered from the surveys completed by our students, we obtain evidence from our faculty in two main ways: (i) assessment reports (i.e., reflexive memos) that are elaborated by professors at the end of each academic term, and (ii) graduate internship reports that are completed by professors affiliated with our *Professional Development Center* (CEDEP, for its acronym in Spanish). These internship reports allow us to evaluate, at the end of the program, the proficiency levels accomplished by our students for selected disciplinary competencies and engineering skills.

Drivers associated with external stakeholders: Industrial stakeholders feed our programs back with the disciplinary and professional skills that they demand. This feedback is collected in several ways, for example through surveys on the performance of engineers and focus groups, and does not necessarily involve companies that employ our programs' alumni. Society stakeholders provide curricular guidelines and best practices (e.g., referents such as IEEE/ACM curricula [12] and CDIO [3]), as well as evidence on the quality of our programs. We collect this evidence through two main evaluation sources: (i) accreditation boards and (ii) the National Professional Test (Saber-PRO, which is comparable to the GRE test), applied by the Colombian Ministry of Education. This test provides comparative evidence on the proficiency levels achieved by our last year students, with respect to the students of similar programs across the country, for selected professional competencies.

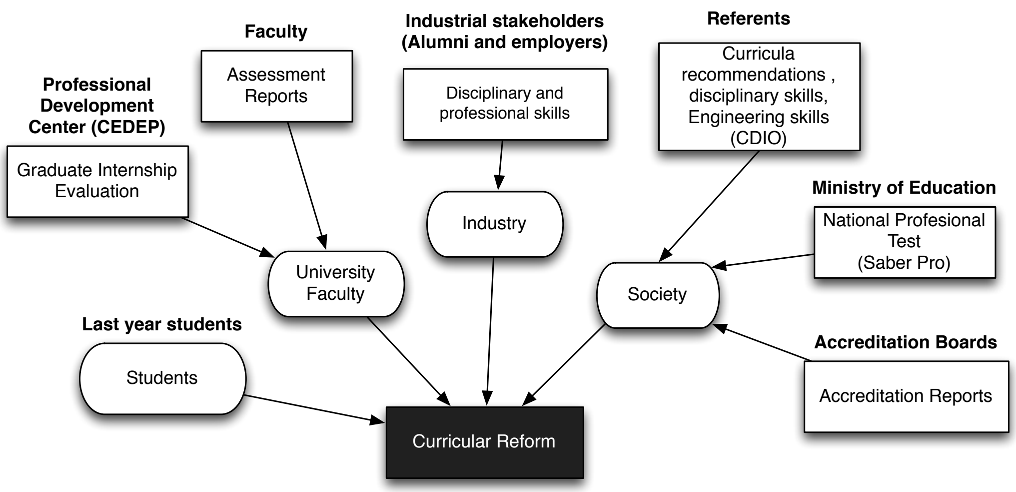

Figure 2 – Stakeholders and drivers of the curricular reforms conducted at Universidad Icesi

5. THE MACRO CURRICULAR LEVEL

This level starts by an evaluation of the evidence collected from key stakeholders. Based on the gathered information, the curricular committee, led by the Program Director, decides whether a curricular reform should take place, and if so, initiates the selection of the input factors to be considered in the reform. In our process, we initiate by studying recommendations from national and international professional referents proper to each program (e.g., ACM/IEEE [12]), as well as mature programs from selected universities. Another input factor we consider is the PEI of our University. The PEI provides the values and general competencies that are expected from the internal community; it also defines the educational model to be followed at the University. The CDIO syllabus [3] together with the aforementioned input factors are employed to create a stakeholders survey, which is applied to a focus group that comprises representatives of employers, alumni, and faculty. The focus group is selected in a way it is formed by professionals with varied years of experience as well as diverse fields of knowledge and professional areas [4][5]. The curricular committee then processes and discusses the survey's results from which the professional profile and the program learning outcomes are specified.

The curricular committee also works on the definition/renewal of the course areas and their correspondent subjects, in order to define the general curriculum structure and the outline of the desired curriculum content along with the learning sequence. With respect to the curriculum structure, we employ the integrated curriculum approach [1] that comprises an introductory course, foundation courses, specialization courses, and capstone courses. As for the curriculum content, although delineating course subjects may be an optional step in other institutions (i.e., professors are autonomous in defining the subjects of the courses they teach), in our implementation process this task is key to guarantee a homogeneous learning experience for students. Being an educational institution that follows the active learning strategy in all academic programs [5][10], the University manages a small-groups policy that facilitates interaction and active participation of students during classes. In consequence, different professors, assigned to several sections, are in charge of teaching the same course. Therefore, defining the general subjects at the macro-curricular level helps keeping a homogeneous learning experience across the different sections.

The last task of this phase corresponds to the mapping between courses and the program learning outcomes. The result is a curricular matrix (cf. Appendix, Fig. 7 and 8) that links each learning outcome and engineering skill to the courses in which they are developed. The matrix also allows us to specify the expected proficiency levels to be achieved at each course, as well as the evolution path of the engineering skills throughout the curriculum. The macro-curricular level is illustrated in Fig. 3. The curricular matrix and the program curriculum structure become the main inputs for the meso-curricular level.

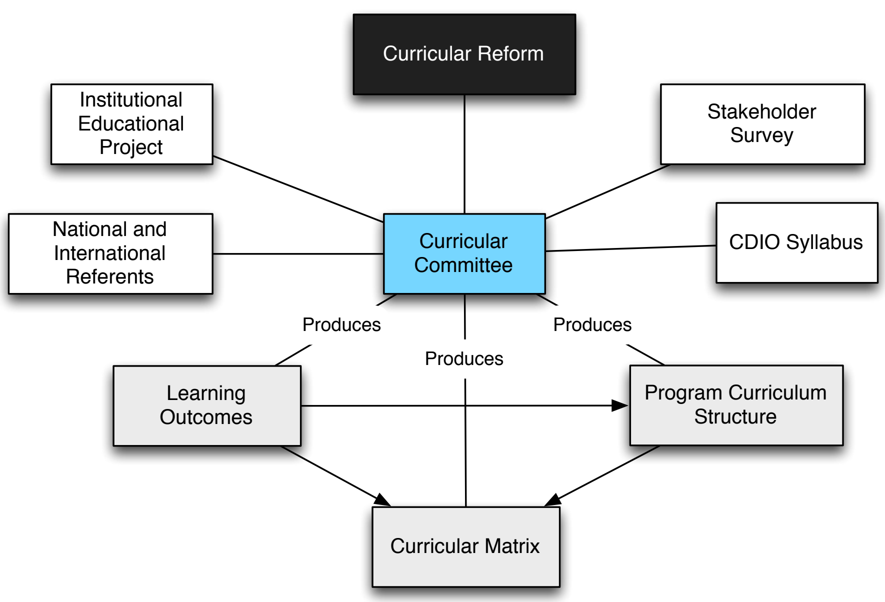

Figura 3 – Macro curricular level

6. THE MESO CURRICULAR LEVEL

The main objective of this level is to produce the course cards: the documents that enable a smooth transition toward the creation of course syllabuses. The course card (cf. Appendix – Fig. 9) is the mechanism we have defined to maintain the consistency between the course intention, defined at the macro-curricular level, and the terminal learning objectives and T&L strategies that will be used to create the course syllabus at the next curricular level. The meso-curricular level is especially necessary in cases in which a single course has different sections taught by several professors. As mentioned previously, course distribution is a common case at Universidad Icesi due to our active learning methodology. However, this level may be omitted in institutions where courses are usually taught by a single professor or when mature faculty members are empowered to create a consistent course syllabus directly from the information provided at the macro-curricular level.

To create the course cards, the curricular committee first uses the curricular structure as an input. The courses are grouped into different knowledge areas [5], so that course cards for an entire group are developed in a coordinated way. We have some areas that are shared between the two programs under review, for example *Basic Sciences and Mathematics*, *Basic Engineering Sciences*, *Algorithms and Programming*, and *IT Project Management*. In most cases, the specialization courses form groups that belong to a single program. For example, the *Software Engineering and Information Systems* area corresponds to the Computing Systems Engineering program, whereas the *Infrastructure* and *Applications and Services* areas belong to the Telematics Engineering program. We have also defined capstone courses for areas in which CDIO learning outcomes can be assessed as an integral part of the course. The areas definition is completed by establishing an area committee. Professors who teach the area's courses form the area committee. A member of the committee is then selected as the area leader who coordinates the creation of the course cards for the entire group.

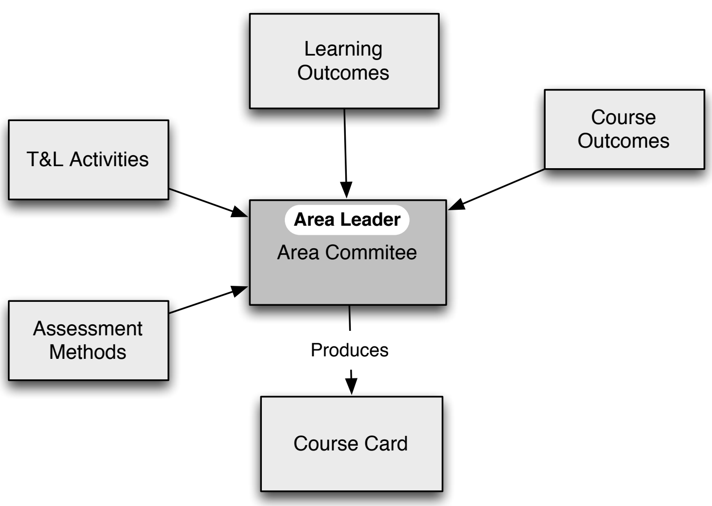

Figura 4 – Meso curricular level

In a second step, the curricular committee informs each area committee about the courses' responsibilities, which are extracted from the curricular matrix. The area committee transforms the list of program learning outcomes and the disciplinary subjects in a set of terminal learning objectives, and records this information in the course cards. In addition, they define the teaching, learning, and assessment strategies to be employed for each terminal objective. During this process, illustrated in Fig. 4, the area leader plays an active role in coordinating the course cards creation as well as guaranteeing the consistency of terminal objectives with respect to the courses' responsibilities defined at the macro-curricular level. The course cards become the guidelines for the development of courses syllabuses at the micro-curricular level.

7. THE MICRO CURRICULAR LEVEL

This level starts with the delivery of course cards to the professors involved in the teaching of courses. As depicted in Fig. 5, the output of this level is the set of course syllabuses. The syllabus serves as a guide for the professor and students to know the specific topics to be discussed in the course, the specific learning objectives to be achieved with each topic, and the grading plan. Since the course card specifies the terminal learning objectives and the general subjects of the course, the professor duties are to extend that information into more detailed topics and the definition of specific learning objectives per topic (or group of topics). Since the terminal learning objectives involve not only disciplinary knowledge but also engineering skills, the specific learning objectives should be consistent and reflect the development of such engineering skills with a proper level of proficiency.

As part of the definition of the course syllabus, the professor also establishes the concrete T&L activities to be developed during the course. In addition, he/she defines the assessment tools (e.g., rubrics). Since not all the professors are experts in curriculum design or in assessment strategies for engineering skills [2], this part of the process may need a faculty development program that may be ineffective in the short term. In such a case, the support from the area leader and from experts associated with the T&L office may help professors select the best teaching and assessment strategies [4].

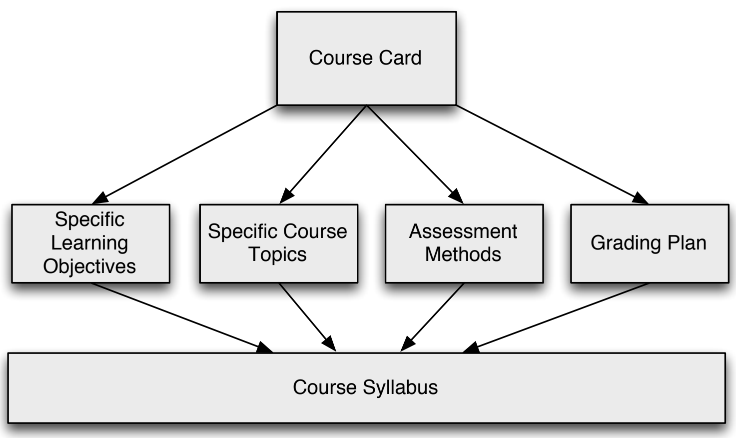

Figura 5 – Micro curricular level

8. THE CONTINUAL IMPROVEMENT PROCESS

Once the term starts, the professor executes the T&L activities that have been planned beforehand. During the term, the professor applies the selected assessment strategies and collects all the evidence necessary to demonstrate the levels of proficiency that are being achieved throughout the course. At the end of the term, the professor is invited to fill out a *Course Reflexive Memo*. This memo helps professors process and organize the information collected during the term. In addition to the reflexive memo, we also employ a *Course Evaluation Survey* that is applied to students in the second half of the term. The survey helps us analyze, among others, aspects such as the students' level of knowledge about the course objectives, execution of the course plan as expected, and commitment of the professor to deliver feedback to students.

The course reflexive memo and the course evaluation survey are discussed with the Department Head and the Area Leader to trigger the definition of corrective actions. As illustrated in Fig. 6, the professor may make changes at the micro-curricular level, e.g., improvements to the course syllabus or the T&L and assessment activities. If necessary, the corrective actions may involve a faculty development plan that helps professors integrate new forms of assessment or improve the assessment tools and T&L methodologies.

In some other cases, the corrective actions may involve revisions at the meso/macro-curricular level. That is the case when the professor asks for a revision of the program learning outcomes that have been assigned to the course. The curricular committee discusses the suggested changes and decides whether a modification should be made in the curricular matrix (e.g., a change in the level of proficiency for a particular outcome, or the elimination of an outcome as a responsibility of a given course). On the one hand, if a change in the matrix is approved, this triggers the modifications required in the lower curricular levels (i.e., changes to the course card and the course syllabus). On the other hand, if the suggested changes are rejected, the faculty development plan is designed in a way it helps professors employ the proper T&L and assessment strategies.

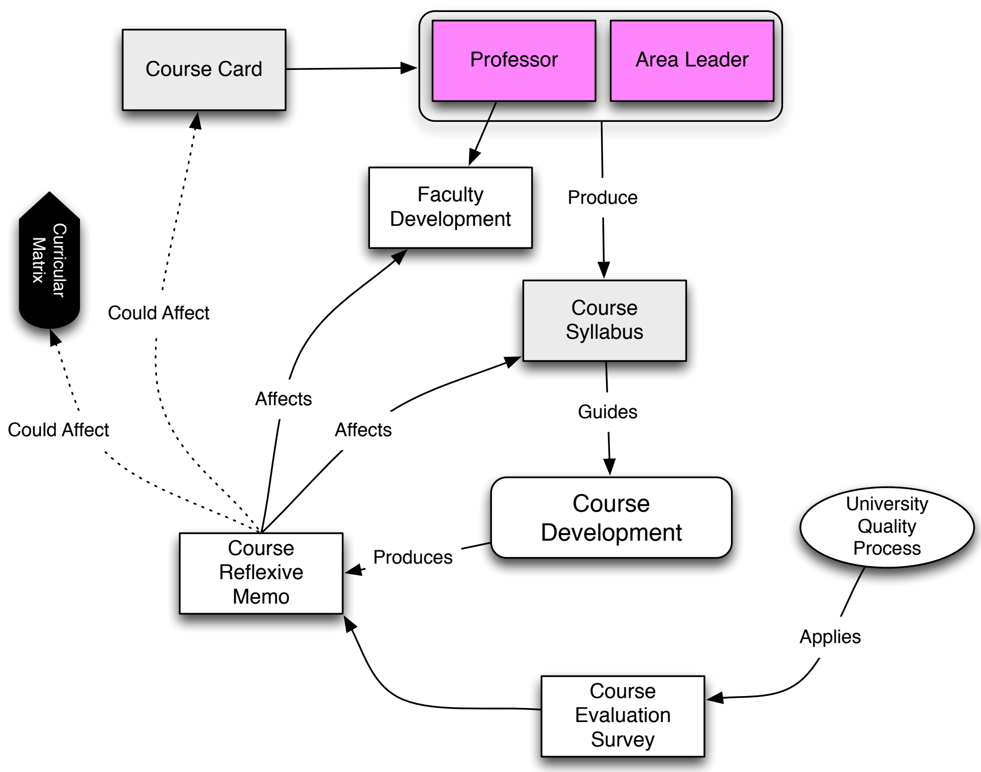

Figure 6 – Continual improvement process

9. LESSONS LEARNED

This section presents a list of factors that were key in reforming the curricula of our Telematics Engineering and Computing Systems Engineering programs at Universidad Icesi. With each factor, we present lessons learned.

Institutionalization of the curricular reform project: Curricular reforms are demanding projects in terms of effort and resources. Furthermore, they have considerable impact on all the key stakeholders of the program as well as on several dependencies of the university. Therefore, and since they imply changes, curricular reforms may generate resistance by some stakeholders or university departments. To counteract this issue, curricular reforms must be directly related to the strategy of the organization so that they can be properly positioned within the institution, and thus gain the commitment of the actors of the process. A way of highlighting the importance of curricular reforms is by justifying the impact that the improvements implemented in the curriculum will have on the vision and strategic goals of the University. An important aspect of the institutionalization process is the socialization of the project and the timely communication of its evolution to key actors and stakeholders, particularly to students and faculty.

Definition of the process and understanding of foundational concepts: Despite the several CDIO implementation cases that have been reported in the academic engineering community, there is not a prescriptive process available that can be applied to any institution, which increases uncertainty and thus the probability of failing when dealing with first time implementations. Therefore, having a reasonably simple, well defined, and documented process, that is understood and accepted by its actors, is absolutely crucial to avoid expensive mistakes. The continual improvement process of the curriculum must be integrated into the general quality assurance process of the institution and programs. An important part of the process is the definition of the key roles, their responsibilities, and the people assigned to each role. In addition to the faculty members and the standard roles within any academic unit (i.e., program directors, department heads, and curricular committees), we highly recommend the definition of committees per course area, which must be coordinated by professors that have an integrated vision of the topics covered by the courses within the corresponding area; and at least one T&L specialist who may act as the project leader under the advising of the dean, program directors and department heads. As part of the process definition, we highly recommend the construction of a comprehensive glossary of terms that can be used to guarantee that all the actors understand the foundations of CDIO, its standards, and the implementation of an integrated curriculum. In particular, we had a difficult time trying to understand the meaning of "integrated curriculum." At the beginning of this process, we interpreted this term as the capability of integrating topics and projects across several courses. As a result, we found no substantial differences between the curricula we were trying to design and the current ones. Only after we understood that an integrated curriculum refers to the definition of learning objectives that naturally mix together professional (i.e., disciplinary) competencies and engineering skills, we took advantage of CDIO for designing engineering learning environments. Finally, we advise to keep the process simple and agile, and implement it incrementally.

Definition of mechanisms for gathering evidence and assessment: Assessment is not as hard and unnatural as it seems to be. Professors gather evidence and assess the performance of their students with every delivered exam, assignment, or project [2]. What is really important is to advance toward the definition of rubrics that support the traceability of learning objectives along the curriculum, starting from the professional competencies of the program and finishing in particular questions or sections of the evaluations. In our process, course cards, course syllabus and rubrics allow us to trace the evolution of learning objectives along the curriculum, term by term. Of course, the development of suitable rubrics demands time and effort. The T&L office can provide professors with catalogs of rubrics applicable to different types of learning outcomes. These rubrics can be collected for example from other institutions, academic publications, and more important, from the faculty members of the same university. Last but not least, it is very common to find competencies that, although are important for your program and worked in the courses, are not that easy to evaluate (e.g., ethics). Do not eliminate these competencies from your curriculum! Sooner or later professors will find suitable mechanisms for evaluating these competencies. If you eliminate them, they may become weaknesses of your program and thus of your alumni.

10. CONCLUSION

In this paper we have presented a detailed guideline for the implementation process of a curricular reform following the CDIO recommendations. Although other CDIO-based curricular reforms have been documented in the past, there is a lack of a detailed definition of the implementation process. Our guideline has been defined throughout our own implementation experience in renovating the curricula of two engineering programs at Universidad Icesi in Cali, Colombia: Telematics Engineering and Computing Systems Engineering. The provided guideline specifies the phases that should be followed to guarantee a consistency across the process, so that decisions made at the highest curricular level (e.g., professional profile and engineering skills) can be carried out up to the most detailed curricular level performed during courses' design. The whole process has been framed in a continual improvement loop, which enables feedback from internal and external stakeholders. Together with the proposed guideline, we have provided information about the key roles needed across the process, as well as the tools and forms that are recommended to facilitate traceability and communication among the different phases. We expect this approach to be a useful guideline that can be replicated and tailored by other institutions.

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BIOGRAPHICAL INFORMATION

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APPENDIX – FORMS AND TOOLS

Competencias	4.4 Diseño															
Objetivos de aprendizaje a nivel de competencias	4.4.1 El proceso de diseño				4.4.2 Las etapas y los enfoques de diseño				4.4.3 Utilización del conocimiento en el diseño				4.4.4 Diseño disciplinario			
Bloques / Materias	I	T1	T2	A	I	T1	T2	A	I	T1	T2	A	I	T1	T2	A
2 INGENIERÍA DE SOFTWARE																
Ingeniería de procesos														1		
Ingeniería de Software			1				1								1	1
Arquitecturas de Software			1								1				1	
Electiva Profesional: Patrones de Diseño de Software								1			1				1	1

Figure 7 – Curricular Matrix of Computing Systems Engineering [Excerpt]: Software Engineering professional area crossed with design-related competencies

COMPETENCIAS	4.5 Implementación											
Objetivos de Aprendizaje de competencias	4.5.3 Implementación de software				4.5.4 Integración hardware/software				4.5.5 Pruebas, verificación, validación, certificación			
Bloques/Materias	I	T1	T2	A	I	T1	T2	A	I	T1	T2	A
INFRAESTRUCTURA												
Interfaces y Arquitectura de Hardware		1					1					
Redes de Computadores I			1	1						1		
Redes de Computadores II			1	1							1	1
Comunicaciones Inalámbricas				1							1	1
Redes Convergentes				1							1	1
Gestión de Infraestructura y Servicios de TI (capstone)												

Figure 8 – Curricular Matrix of Telematics Engineering [Excerpt]: Infrastructure professional area crossed with implementation-related competencies

COURSE CARD

Course Basic Information

- Code - Name:
- Requisites:
- Credits:
- Is requisite of:

Course content
Subject 1
Subject 2
....

Terminal Learning Objectives (associated to Program Learning Outcomes and proficiency level)

Terminal Learning Objective	Program Learning Outcome
Terminal Objective 1	Competencie x.y.z
Terminal Objective 2	Competencie x.y.z Competencie x.y.z
Terminal Objective 3	Competencie x.y.z Competencie x.y.z

T&L and Assessment methods

Terminal Objective	Pedagogical strategy to be employed	Assessment method
Terminal objective 1	Case study PBL Debates Etc. . .	Peer evaluation . . . .
Terminal objective 2	.	.

Figure 9 – Course Card Form