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A Curricula Model for Supporting a Design-Centric Computing Engineering Education*

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The constant evolution present in the information and communication technologies (ICT) as a result of the changing environment is a big challenge for computing engineering (CE) professionals that face a demand for solving increasingly new and complex technological problems. This technological evolution imposes, among others, a process evolution within the organizations, the information multiplication to be integrated and processed, an increase in competitions to respond faster to global needs, and an increasing demand for systems integration. As a result, CE programs have an undeniable and constant necessity to evolve their curricula to keep up to date. We have defined, put into production, and validated a curricula design model based on competences to facilitate the design and implementation of CE programs. The frame for competence definition is stable, allowing a fast adaptation to the continuous change. The curricula design model turns around a set of competences defined in terms of the life cycle of problem resolutions, which is structured around projects. We illustrate how to design project-based CE programs that aim students to incrementally develop competences for understanding complex problems and for designing solutions around them.

Keywords: curricula design model; project-based; design-centric education; assessment method

1. Introduction

The constant evolution present in the information and communication technologies (ICT) is a big challenge for CE professionals that face a demand for solving increasingly new and complex problems. This makes evolving processes, multiplying information for integration and management, and increasing graduate competitions respond faster to global needs. This fact also motivates the need to design CE programs allowing curricula adaptations to keep aligned with the accelerated and constant change. In particular, these programs must tend to produce graduates with strong competences for understanding complex problems and for designing solutions around them.

We have defined a curricula design model to facilitate the design and implementation of CE programs structured in terms of competences specific to this discipline. The frame for competence definition is stable, allowing a fast adaptation to the continuous change, in contrast to curricula designs guided by knowledge areas. The curricula design model supports a project-based learning [1] by defining and grouping a set of competences according to the life cycle of problem resolutions. These types of competences can be considered as the main interactions of graduates in the CE practice typically framed into projects. Because of this, we defined a process for creating and evaluating program designs composed of courses that aim to develop the competences required to successfully face each phase in the project life cycle. The curricula design model is composed of a reference framework that defines the core elements required for curriculum design in terms of competences, and a methodology to instantiate it into a new program design that satisfies a specific professional profile.

The design premises and generalities of the curricula design model are presented in [2]. In addition, this paper focuses on the key design-centric professional educational objectives proposed by the reference framework, details the specific design-centric learning goals to be developed and evaluated in the courses, presents a detailed validation scenario of creating a design-centric engineering program based on the curricula design model, and illustrates the application of a quality assurance system to validate the achievement of the competences defined in the target professional profile of the new design-centric program.

The new design-centric program was implemented at the University of Los Andes in Colombia. Within this implementation, we present the competences defined for the courses and the evaluation performed to verify that these competences were achieved. The results of this evaluation showed that the competences defined by the curricula design model, and specially the design-centric competences, were effectively assessed, facilitating the definition of potential improvements for the courses.

The paper is structure as follows. Section 2 introduces the main elements of the curricula design model. Section 3 details the design-centric specific competences incorporated within the refer-

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ence framework. Section 4 presents a design-centric engineering program designed by using the curricula design model. Section 5 presents the results of evaluating the achievement of competences defined in the curricula design. Section 6 discusses on related work. Section 7 concludes and discusses on potential research for future work.

2. The curricula design model

The curricula model aims to implement design-centric programs in which: 1) the curriculum structure is guided by competences and not by knowledge areas, 2) the competences are conceived as vital in the life cycle of problem resolutions, which is structured around projects, 3) a professional profile is designed precisely and guides the curriculum design, 4) a set of project types scope the professional participation in CE activities, 5) the competences are generated incrementally across the curriculum, 6) a program design is evaluated to verify that graduates are acquiring a desired professional profile, and 7) there is a common language that facilitates the communication between all the actors involved in curriculum designs of CE programs [2].

This project-based curricula model focuses on converging engineering education and practice by means of defining clear and complete program goals. The curricula design model is composed of a reference framework that defines the core elements required for curriculum design in terms of competences, and a methodology to instantiate it into a new program design that satisfies a specific professional profile.

2.1 Reference framework

The reference framework discusses a set of professional and personal competences at different levels that define the participation of CE graduates in different phases of a project. These competences allow students to understand an organization, its environment, and its problems, to define projects for solving the identified problems, to specify the global aspects of a solution, to provide a detailed design of a solution, to construct the designed solution, and to assembly and administrate the solutions.

The reference framework is composed by four elements. First, an ontological model introduces the concepts related with the problem resolution life cycle and their relations (i.e. problem, beneficiary, provider, solution, and project). Second, a formation space scopes the courses and the academic and research activities in which the graduates can develop professional and personal competences. The competences (e.g., effective communication) required in any profession are framed within the

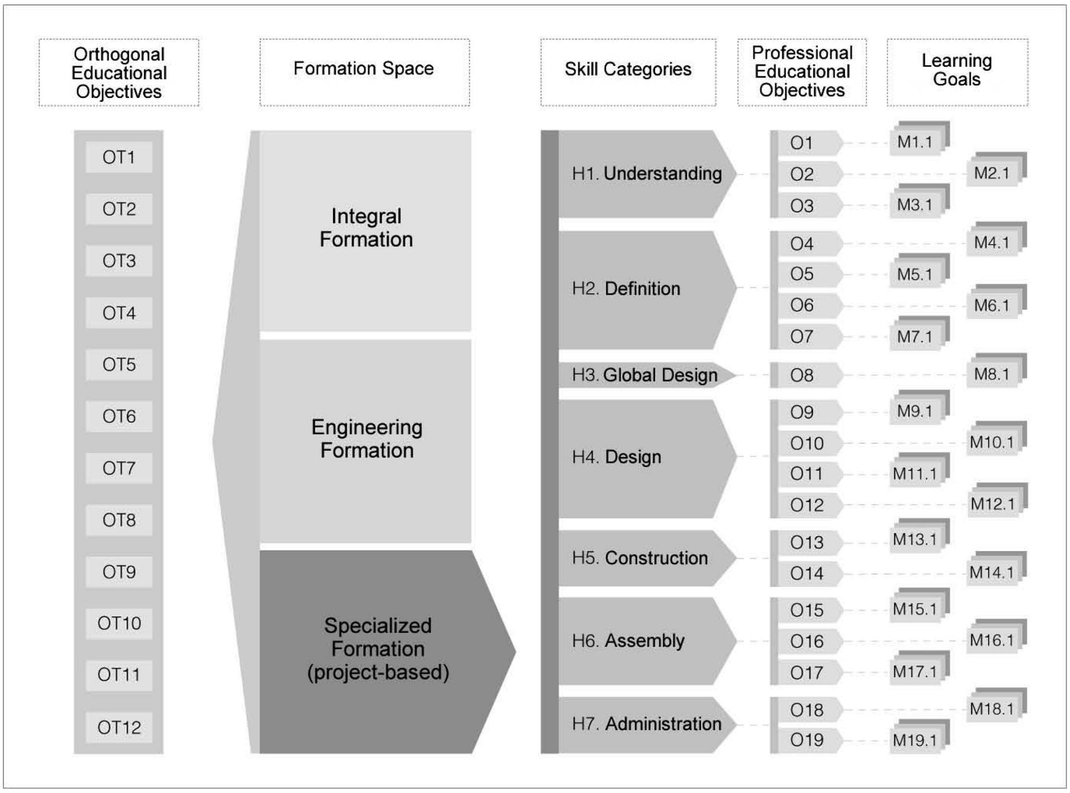

Fig. 1. Elements within the competence map.

integral formation, the competences common to engineers (e.g., mechanical, chemical) are framed within the engineering formation, whereas the competences specific to CE professionals are framed within the specialized formation. Third, a competence map groups, defines, and refines within three levels the professional and personal competences that can be used to define a desired CE professional profile. Finally, the curricular structure defines the curricular layers to frame the CE specific courses in proficiency levels.

Figure 1 illustrates the competence map framed within the formation space.

The professional competences within the specialized formation are classified in a set of 7 skill categories (SCs) that define the participation of a CE professional in different phases of a project. These categories group a set of 19 professional educational objectives (PEOs) that define the possible competences to develop in the students. These educational objectives are refined into 62 learning goals (LGs) that have to be evaluated of the students. The competence map also defines a set of 12 orthogonal educational objectives with personal competences that are transversal to the formation levels.

Within the reference framework there are two skill categories that support CE programs with a design-centric education (H3 and H4 in Fig. 1). Both skill categories comprise a set of 5 PEOs (O8—O12 in Fig. 1) which contains a set of 19 LGs (M8.1-M8.7, M9.1-M9.4, M10.1-M10.2, M11.1-M11.3, and M12.1-M12.3 in Fig. 1). The design-centric competences are detailed in the next section.

Table 1 summarizes the distribution of competences within the specialized formation of the competence map and highlights the contribution of design-centric competences.

Figure 2 illustrates the curriculum structure framed within the formation space.

The integral formation level refers to general-

Table 1. Professional competences within the reference framework

Skill Category	Number of PEOs	Number of LGs
H1. Understanding	3	13
H2. Definition	4	11
H3. Global design	**1**	**7**
H4. Design	**4**	**12**
H5. Construction	2	9
H6. Assembly	3	6
H7. Administration	2	4

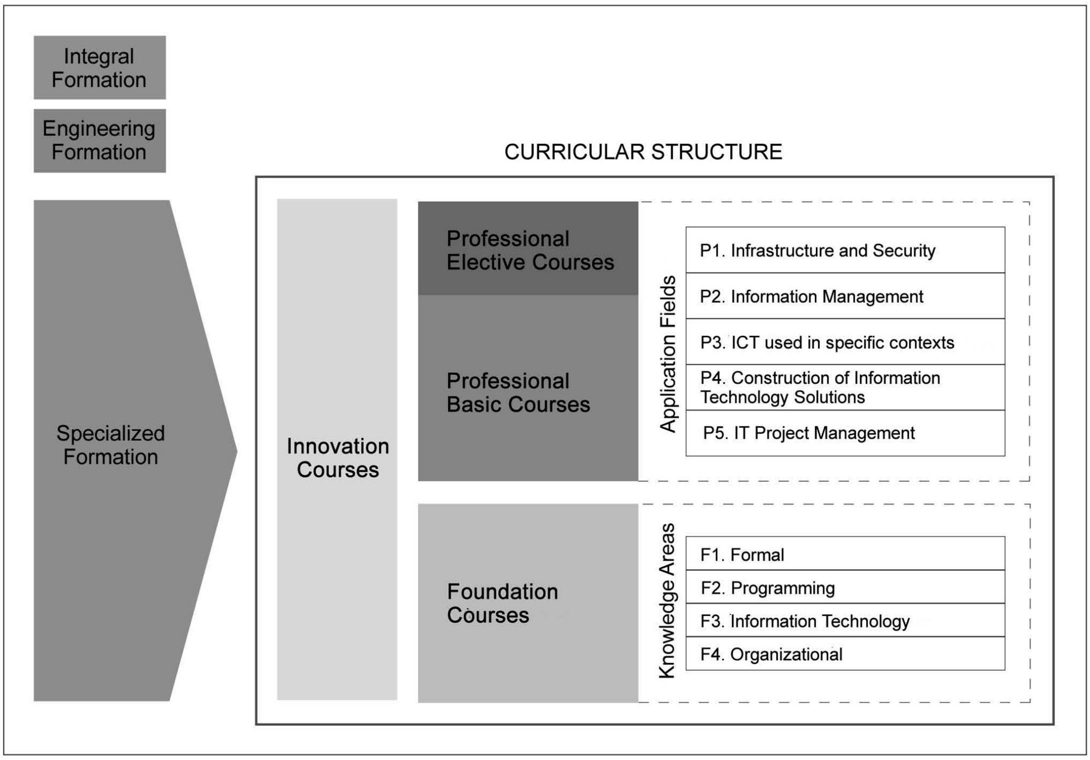

Fig. 2. Elements of the curricular structure.

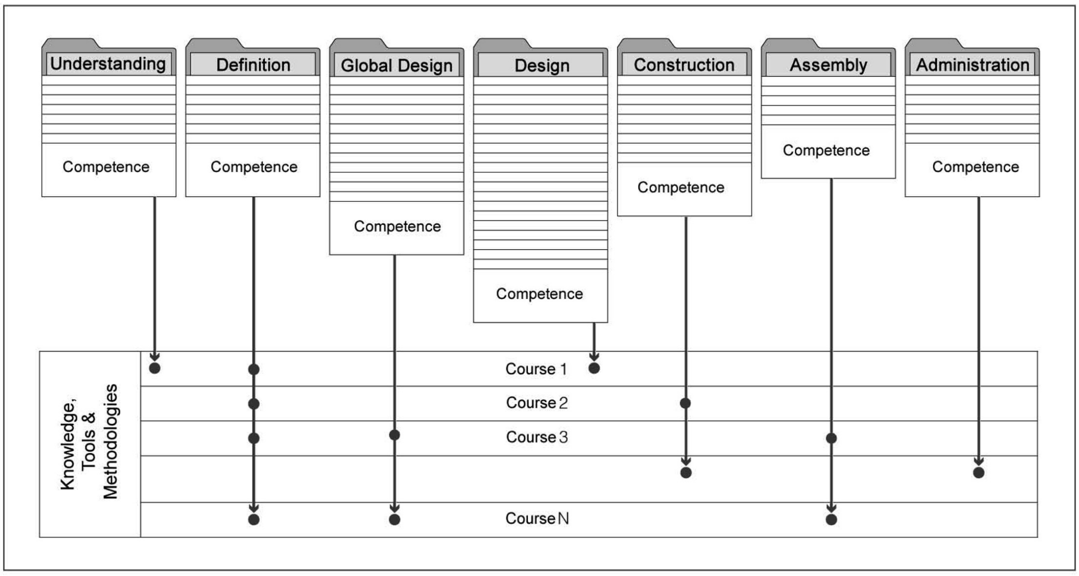

Fig. 3. Relation between competences and specific knowledge.

purpose courses (e.g., arts and humanities), whereas the engineering formation level refers to courses of engineering foundation and basic sciences. The specialized formation level frames the CE specific courses in four proficiency levels: foundation, professional basic, elective professional, and innovation. The foundation courses generate competences and give fundamental knowledge in four CE knowledge areas (e.g., information technology). The professional courses are grouped into five application fields (e.g., infrastructure and security) representing the project types that graduates in a CE program must face in their professional life. The innovation courses generate competences by innovating with information and communication technologies (ICT).

The curriculum structure also defines the main application fields and knowledge areas involved in these proficiency levels, defined according the local needs and the global tendencies.

The generation of competences in the students is a slow process that requires being addressed incrementally across the formation space. Figure 3 illustrates how all the courses collaborate to incrementally generate competences semester by semester.

The knowledge incorporated within the courses is adjusted according to the application field evolution. This facilitates the definition of specific professional profiles. There is an explicit relation between competence and knowledge as illustrated. The knowledge evolves all the time whereas the frame for competence definition remains stable.

2.2 *Implementation methodology*

The implementation methodology guides the curricula design stakeholders in defining a desired professional profile for the graduates of an academic institution. This is done by selecting a subset of PEOs (cf. competence map in section 2.1) and by indicating for each one the depth level (percentage of time) to be generated. The selected competences are used to design the courses indicating their contribution to the desired professional profile. Every course must be designed at the beginning of an academic term.

Figure 4 illustrates a process we have defined to

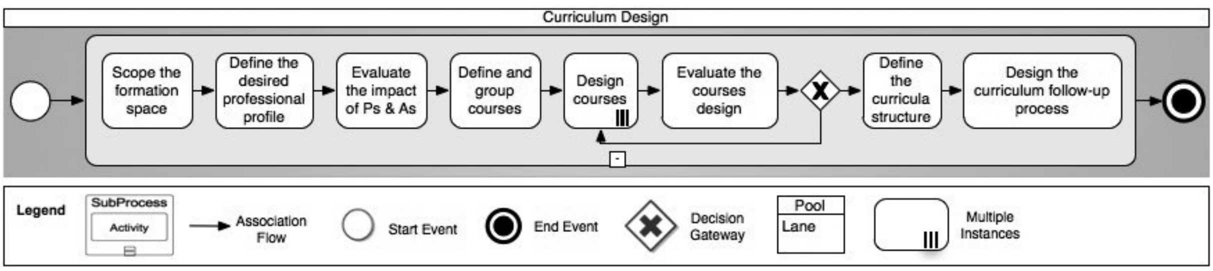

Fig. 4. Curricula design process.

facilitate the definition of a new curriculum design based on competences.

This process can be executed by any education institution to facilitate the definition of a new curriculum design by guiding how to: (1) scope the participation percentage or credits number for each formation level (i.e., integral, engineering, specialized) within the formation space, (2) define and represent a curve in the competence map in a desired professional profile involving multiple faculties of the program, (3) define the contribution value of the application fields and knowledge areas on the desired professional profile, (4) define the specialized formation courses according to the expected contribution of application fields and knowledge areas, (5) declare the design in terms of competence of the specialized courses in order to establish their contribution to the desired professional profile, (6) evaluate the course design to verify and align them with the designed professional profile, (7) propose and graph the structure of the new curriculum, and (8) design the curriculum follow-up and evolution processes. These activities are illustrated in sections 4 and 5 through a validation scenario.

3. Design-centric competences

Table 2 presents in detail the key design-centric professional educational objectives and learning goals proposed by the reference framework[1]. The PEOs and LGs within the following skill categories are out of the scope of this paper: understanding, definition, construction, assembly, and administration.

These design-centric competences can be specialized to be incorporated in the design of a course. However, not all of them have to be selected by the design responsible, just the ones that need to be generated and evaluated in the course.

4. Validation scenario: a design-centric engineering program

We have validated the proposed model by creating the curriculum design for the CE program at the University of Los Andes. The actual formation space for the curriculum is 137 credits of which 72 credits or 24 courses (52%) are targeted to the specialized formation.

Figure 5 illustrates the professional profile designed and obtained after consolidating the selection and weighting of competences done by faculty members. The depth level corresponds to the percentage of time spent by the curriculum design to generate a competence. Thus, the curriculum is designed to spend 43.8% of the time to generate design-centric competences.

In particular, this professional profile illustrates a trend to design-centric competences such as the specification of global aspects of a solution (H3. Global design), and mainly the detailed design of a solution (H4. Design). Another trend in this profile is towards competences for implementing a solution. Other competences are not considered too relevant in the graduates' formation.

The resulting professional profile guides the emphasis for defining courses within the application field and knowledge areas. Table 3 presents the impact of knowledge areas and application fields, assigned within a 0 .. 10 scale, to the skill categories of the professional profile. The impact of knowledge areas and application fields to the design-centric competences are highlighted. This impact definition guides the course design by indicating the emphasis in the to be developed competences, depending on the knowledge area. For example, we can observe the high relevance to develop detailed design competences for the courses within the *Information Management* application field and for the courses within the *Formal* knowledge area.

Based on this impact analysis we defined 8 fundamental courses distributed within the 4 knowledge areas, 10 professional courses distributed within the 5 application fields, 3 elective courses, and 4 innovation courses[2].

The course indication defines the professional competences (SCs and PEOs) qualified with a percentage value portraying the emphasis given by the course to generate these competences. For instance, Table 4 summarizes the design declared for the *Transactional Systems* course in terms of competences and highlights the contribution of design-centric competences. It is important to mention that not every competence category (SCs, PEOs, and LGs) should be incorporated within a course. Additional information is considered during a course design such as the description of the specific goal of the course in terms of each selected PEO. These specific goal references one of the LGs within that PEO[3].

The design of this course shows a high contribution of the course to generate design-centric competences (i.e., O8 .. O10 PEOs). The impact of all course designs in the professional competence profile is established by assigning the competence

[1] A complete description of the competences within the reference framework elements can be found at http://sistemas.uniandes.edu.co/~modelocurricular/

[2] The detail of the courses design can be found at http://sistemas.uniandes.edu.co/CursosCurriculo/.

[3] There is a wiki with the description of each course and its contribution in terms of competences to the designed professional profile.

Table 2. Design-centric competences within the reference framework

Skill Category			H1. Understanding
			H2. Definition
			H3. Global design
	Professional Educational Objectives		O8. Design and justify a viable approach to solve a problem. This approach must take into account the general structure of the solution and its governance needs once it is built.
		Learning Goals	M8.1 Understand the different dimensions and elements which take part in a solution and the impact of the decisions taken on them.
			M8.2 Analyze alternatives by comparing and selecting elements that make up a solution so that it is feasible in the context of a problem, beneficiary, and supplier.
			M8.3 Use strategies to define the general structure of a solution (e.g., top-down design), explicitly identifying its components and the relationships between them and other elements which are part of the project context.
			M8.4 Validate with a beneficiary and justify the general structure of a solution in terms of a problem and of the project definition context.
			M8.5 Design the process of building a solution by including the cycles which make up the process, by refining cost, resource, and time estimates, and by following standards.
			M8.6 Define the management needs of a solution, making explicit management diagrams which guarantee an adequate operation.
			M8.7 Recognize and use skillfully existing and pertinent languages and standards relevant to specify the dimensions of the solution.
			H4. Design
	Professional Educational Objectives		O9. Design and justify the solution design according to the global specifications and with the required detail to construct it.
		Learning Goals	M9.1 Recognize and use existing languages and standards which allow a detail specification of the solution design.
			M9.2 Follow a progressive refinement methodology starting with global structure components and reaching design elements with high levels of detail.
			M9.3 Identify and include in the design existing elements which can be adapted to be part of the solution.
			M9.4 Specify the components that must be constructed, acquired, or adapted by considering functional and non-functional points of view and showing that they meet the established requirements to justify the taken decisions.
			O10. Design solution testing plans for individual parts and for the entire system which must cover various aspects of the solution (e.g., functional, load).
		Learning Goals	M10.1 Know the formalisms, methodologies, and technologies to define and build testing plans.
			M10.2 Validate testing plans taking into account the context of the beneficiary and in terms of global and specific requirements of a project.
			O11. Design a process to build the solution with a sufficient level of detail so that said process may be executed and detailing the global plan so that it meets the possibilities and restrictions of the supplier.
		Learning Goals	M11.1 Define the cycles and stages which must be followed in the construction of a solution by assigning to each of them time and resources and by specifying the deliverables to be produced.
			M11.2 Know and be able to express the building process of a solution using the adequate languages and standards.
			M11.3 Define the way in which the results obtained in each construction stage of the solution will be measured and quantified so that it is possible to trace the project.
			O12. Design delivery and operationalization processes for a solution and its management under the beneficiary environment.
		Learning Goals	M12.1 Define the delivery protocols for a solution under the beneficiary.
			M12.2 Define the plans for beginning the operation of a solution which must include organizational change, migration schemes, user training, and contingency plans.
			M12.3 Detail the management process of a solution using existing languages and standards to define aspects such as tasks, resources, and incidents management.
			H5. Construction
			H6. Assembly
			H7. Administration

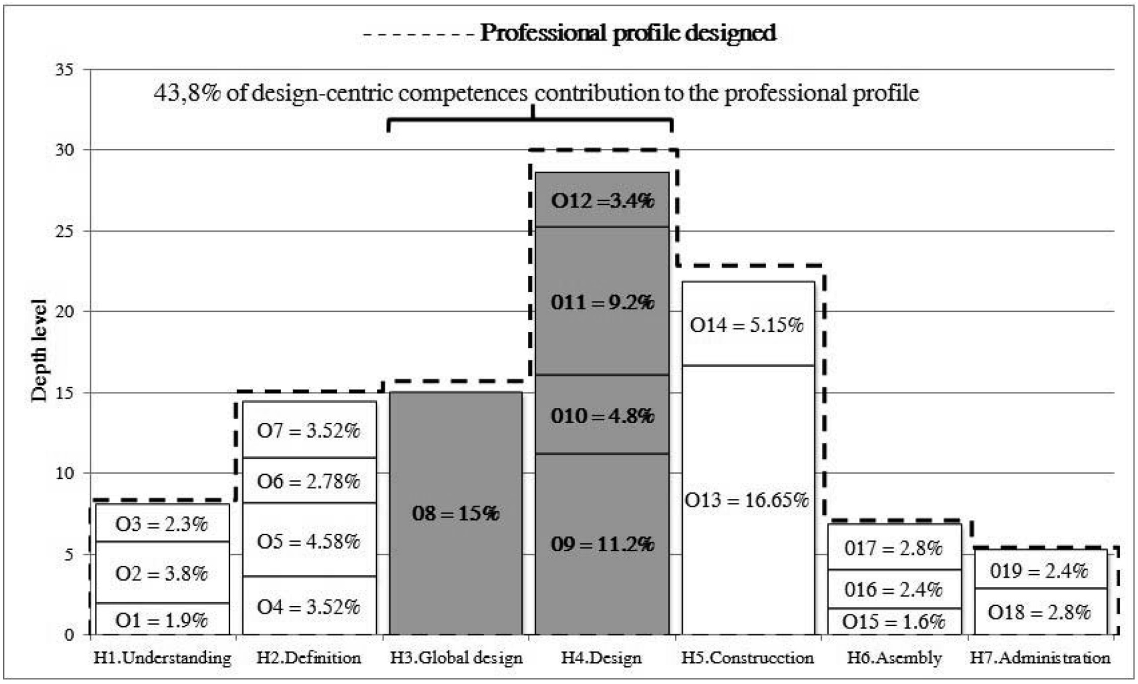

Fig. 5. Professional profile for graduates at the University of Los Andes.

Table 3. Impact definition of application fields to design-centric competences

	H1. Understanding	H2. Definition	H3. Global design	H4. Design	H5. Construction	H6. Assembly	H7. Administration
P1. Infrastructure and security	1	1	2	4	2	0	1
P2. Information management	0	0	2	**6**	3	0	2
P3. ICT used in specific contexts	3	3	3	2	1	1	0
P4. Construction of IT solutions	0	1	2	3	3	4	0
P5. IT project management	0	2	0	2	2	1	2
F1. Formal	2	3	1	**7**	2	0	0
F2. Programming	0	1	3	3	7	1	0
F3. Information technology	0	1	0	2	2	0	0
F4. Organizational	1	1	1	0	0	0	0
Total	**8**	**14**	**14**	**29**	**23**	**7**	**5**

Table 4. Example of a design-centric course design

SC	H1			H2				H3	H4				H5		H6			H7	
PEO	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15	O16	O17	O18	O19
Depth level				5				28	20	14			28					5	

weights, declared in the course design activity, to each PEO. The sum of all competence weights for each course and of the average weight of each PEO for all courses must be 100. The average weight for each skill category can be computed from all its related PEOs average weights in order to obtain the actual professional profile, which can be illustrated as a curve in the competences space. Thus, the course designs can be evaluated to illustrate the differences between the designed and obtained professional profiles. The differences between both profiles guide the types of improvement actions to be applied such as iterating on the course designs to obtain the desired profile, or modifying the desired professional profile. For the specific case of the CE program at the University of Los Andes, the evaluation of the resulting profile caused small variations on the originally defined professional profile.

Each course develops partially the competences defined in the professional profile along the semesters; therefore, a course can be also expressed as a curve in the competence space, while the sum of all course designs must complete the expected profile. Thus the course designs can be evaluated in terms of their contribution to the professional profile.

Figure 6 illustrates the contribution of the courses

Design-centric competences

	H1. Understanding	H2. Definition	H3. Global Design	H4. Design	H5. Construction	H6. Assembly	H7. Administration
P1. Infrastructure and Security	1,4	1,1	2,9	2,6	2,9	0,0	0,3
P2. Information Management	0,4	0,6	2,3	4,1	3,4	0,0	0,4
P3. ICT used in specific contexts	5,7	4,7	3,8	1,1	1,1	0,3	0,0
P4.Construction of Information Technology Solutions	0,3	1,7	2,3	2,3	3,8	0,7	0,0
P5.IT Project Management	0,5	2,3	0,0	1,4	0,8	0,2	0,3
F1. Formal	1,3	6,2	1,4	4,9	2,9	0,0	0,0
F2. Programming	0,0	2,0	4,0	1,9	8,6	0,1	0,0
F3. Information Technology	0,0	1,8	0,3	1,2	2,2	0,0	0,0
F4. Organizational	2,2	1,8	1,5	0,0	0,0	0,0	0,0

Fig. 6. Course contribution to design-centric competences of the professional profile.

to the professional profile, which are grouped by application fields and knowledge areas. Each curve details the specific percentage of time that each group of courses spend to generate design-centric competences. For example, 6.4% of the time required to generate the design-centric competences of the professional profile, is a contribution of the information management courses.

These competences are materialized in a different way within each course depending on the project types, and implying different knowledge areas, tools, and methodologies.

5. Evaluating the achievement of design-centric competences

Once the curricula is designed and implemented, it is necessary to evaluate its execution in order to verify that the courses are generating the defined competences. This was done through the adoption of a quality assurance system named Calis [3] to include a formal analysis to the resulting curriculum.

The following sections describe the activities for assessing the achievement of the design-centric curriculum created at the University of Los Andes.

5.1 Quality assurance system

The Calis system instantiates the general a..k ABET student outcomes [4] into a set of 25 student outcomes specific to the CE discipline. Thus student outcomes can be interpreted in the same way when applied to CE programs. It also defines an evaluation process that uses the regular course evaluation as main asset to measure and evaluate the student outcomes directly without any complementary tasks.

Each Calis student outcome is composed of four elements: (1) a first level outcome corresponding to a ABET student outcome (i.e., an ability to apply knowledge of mathematics, science, and engineering), (2) an explanation of this outcome in terms of CE, (3) second level outcomes conforming a first level outcome (e.g., model, design solutions, evaluate solutions), and (4) third level outcomes that are explanations of second level outcomes (e.g., design of solutions from specifications in knowledge domains such as logic, software engineering, and networking).

Based on the course information (cf. Table 4 in Section 4), Calis defines an evaluation plan as a matrix that represents how much (percentage) each evaluation indicates the course contribution to the PEOs. Thus, the sum of all evaluations for the course and for each PEO must be 100%. This also defines how learning goals are evaluated by the considered evaluations.

Calis measures the achievement of student outcomes directly and indirectly during the courses execution and at the end of the career. We used Calis measurements taken in the courses to evaluate the achievement of professional competences, defined at the course registration time, at the end of each academic term.

A course responsible collects direct measurements for each course section by reporting the course evaluations in a matrix with the evaluation results of students who finished the course. The evaluations results are taken from three random students chosen at the beginning of the term, and from the best and worst student results. This matrix assesses the performance, with a range between 0 and 5, of the student in a planned evaluation. Indirect measurements are taken at the end of a term by questioning students about the way the perceived the course. The questions of the survey are related to first and second level SOs and their answers are given in a scale from 1 (poor) to 4 (excellent).

5.2 Evaluation process and results

We correlated the professional educational objectives of the curricula design model with the second level Calis student outcomes to assess the achievement of the target professional profile.

Table 5 illustrates this correlation through a matrix in which each value is a percentage indicating the impact of the professional educational objectives (O1 .. O19) to student outcomes (a1 .. k1). The correlation of design-centric competences with Calis subtended outcomes is highlighted. The sum of all values of a row is 100%.

Based on the correlation table, Calis calculates the percentage contribution of evaluations with the corresponding student outcomes. It also computes the achievement of student outcomes in the scale 1 (worst) .. 4 (best), considering measurements greater or equal to 3.0 as satisfactory (S), measurements greater than 2.5 but lower than 3.0 as satisfactory-low (S-), and measurements lower than 2.5 as unsatisfactory (U). U and S- measurements indicate some problematic aspects within the course that must be considered for improvement.

Table 6 summarizes the course SOs' direct and indirect measurements taken and analyzed in 2010-20 for the course Transactional Systems. This table emphasizes the measurements of student outcomes corresponding to design-centric competences (cf. O8 .. O12 design-centric competences in Table 5). A measure in **bold** represents an assessment with S- grade whereas a measure in *italics* represents is assessed with U grade. Blank values mean student outcomes that were not considered relevant in the course declaration.

The resulting direct measurements indicate that mostly the design-centric competences are satisfactory achieved for this course. It also shows that O8 and O9 PEOs have a low level of satisfaction since the student outcomes a2 and j1, which are related with them (cf. Table 5), were measured with a value lower than 3. Both outcomes were achieved with a 74.25% of satisfaction which corresponds to a 81.44% of satisfaction of O8 and O9 PEOs in general. Thus, the achievement of O8 corresponds to 22.8% in terms of the specific contribution defined for the transactional system course (cf. O8 = 28% in course design Table 4). In the same way, the achievement of O9 corresponds to 16.28% in terms of the specific contribution defined for the transactional system course (cf. O9 = 20% in course design Table 4).

The resulting indirect measurements illustrate values that are higher than 3 for outcomes not

Table 5. Correlation between design-centric competences and student outcomes

Calis / PEOs		A			B		C			D				E			F		G			H	I		J	K
		A1	A2	A3	B1	B2	C1	C2	C3	D1	D2	D3	D4	E1	E2	E3	F1	F2	G1	G2	G3	H1	I1	I2	J1	K1
H1	O1	35					35												10	10	10					
	O2	30				10	10							5	5				10	10	10				5	5
	O3	35					15	20											10	10	10					
H2	O4	30					15		15					40												
	O5	10					20	20	15						10	15									5	5
	O6			30		20	20								10							20				
	O7	10			35			35								20										
H3	O8		**20**		20		10	20	10							10									5	5
H4	O9		**20**		20		10	20	10							10									5	5
	O10			30			20	20	20							5										5
	O11						25	35	30							5										5
	O12							45	45							5										5
H5	O13				50		40									5										5
	O14							30							5	5				30	25					5
H6	O15																		40	40	20					
	O16						40			40			20													
	O17																		40	40	20					
H7	O18					50		10							10				10	10						10
	O19	20				15	15	10	10													25				5

Table 6. Direct measurements obtained for the Transactional Systems course

Student Outcomes	a1	a2	a3	b1	b2	c1	c2	c3	d1	d2	d3	d4	e1	e2	e3	f1	f2	g1	g2	g3	h1	i1	i2	j1	k1
Direct Measurements	3,23	**2,97**	3,12	3,05	3,05	3,08	3,00	3,03					3,23	3,05	3,01			3,05	3,05					**2,97**	3,03
Indirect Measurements	3,48	2,12	3,79	3,70	3,85	3,79	3,24	3,88	3,30	3,39	3,09	3,42	3,67	3,76	3,76	3,33	3,48	2,12	3,79	3,70	3,85	3,79	3,24	3,88	3,30

considered within the course design. This indication can be used to decide if it is necessary to change the specific goals considered within a course design. These measurements also show a high difference (> 20%) between some direct and indirect measurements of student outcomes (i.e. d, f, h, i SOs). However, these differences do not affect the consistency of the results since they are present for outcomes not considered within the course design. The analysis of the causes and improvements to allow the achievement of these competences are out of the scope of this paper.

6. Related work

The main motivation to define a new curricula design model in CE programs is to generate a common language highly adopted by institutions in Colombia and also in international environments. We have compared our curricula design model with different curricula approaches in engineering education.

The CDIO (Conceive, Design, Implement, and Operate) initiative [5] has defined a set of learning outcomes for designing and evaluating engineering programs. These learning outcomes are described in a document named CDIO Syllabus—A Statement of Goals for Undergraduate Engineering Education [6]. These objectives are classified in four categories (technical knowledge, personal attributes, interpersonal skills, and the skills specific to the engineering profession—CDIO), which are expanded in three levels. The CDIO approach defines objectives for engineering programs in general, in contrast to our design model that defines competences specialized to CE programs. However, there is a close relation since both are based on competences.

Table 7 illustrates the relation we have established between the PEOs and the learning outcomes of the CDIO approach. We identified a direct relation between design-centric competences within the competence map (O8 .. O12) and design-centric competences of the CDIO approach. This relation is highlighted in the table. Considering this relation the CDIO approach could be used for the assessment of a new program designed with our curricula

Table 7. Relation between PEOs and the CDIO syllabus

		Skill categories and Professional Educational Objectives																		
		H1			H2				H3	H4				H5		H6			H7	
CDIO Syllabus		O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15	O16	O17	O18	O19
1	**Technical knowledge and reasoning**																			
1.1	Knowledge of Underlying Sciences	●	●	●	●	●	●	●	●	●	●									●
1.2	Core Engineering Fundamental Knowledge	●	●	●	●	●	●	●	●	●	●									●
1.3	Advanced Engineering Fundamental Knowledge		●			●			●	●	●	●	●	●	●	●			●	●
2	**Personal and professional skills and attributes**																			
2.1	Engineering Reasoning and Problem Solving		●		●	●	●	●	●	●	●	●	●	●	●				●	
2.2	Experimentation and Knowledge Discovery		●				●	●	●	●				●					●	●
2.3	System Thinking	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
2.4	Personal Skills and Attitudes																			
2.5	Professional Skills and Attitudes																			
3	**Interpersonal skills: teamwork and communication**																			
3.1	Teamwork																●			
3.2	Communications	●		●											●	●				
3.3	Communication in Foreign Languages																			
4	**Conceiving, designing, implementing, and operating systems in the enterprise and societal context**																			
4.1	External and Societal Context		●			●	●		●	●										●
4.2	Enterprise and Business Context	●	●	●																
4.3	Conceiving and Engineering Systems				●	●	●	●												
4.4	Designing								●	●	●	●	●							
4.5	Implementing													●	●					
4.6	Operating															●	●	●	●	●

design model. Thus CDIO syllabus can provide the design model with the specific engineering competences, while the design model is a specialization that defines a competence map and a curricular structure specific to the CE discipline.

The CDIO initiative also defined 12 standards to rich these objectives. Additionally, our model provides a curriculum structure and a strategy to materialize the competences into a curriculum design.

The Accreditation Board of Engineering and Technology (ABET) [4] defines a set of outcomes (a .. k) to be measured within engineering programs. As presented before, we have adopted a quality assurance system named Calis that instantiates the ABET outcomes into CE outcomes to evaluate the execution of a program design. The PEOs of our reference framework have been related with the Calis outcomes to measure the achievement of the competences defined in the professional profile of graduates at the University of Los Andes, and also to indirectly measure the achievement of ABET outcomes.

The Association for Computing Machinery (ACM) has defined curricular guides and recommendations for CE programs [7]. In contrast to the ACM model that is based on knowledge, the proposed model is based on competences for curriculum design processes. The ACM defines the following 5 computing disciplines: Software Engineering, Computer Science, Information Systems, Information Technology, and Computer Engineering. Our curricula design model can be used for the curricula designs framed in the first four disciplines. However, it is not directly applicable to create Computer Engineering curricula designs since the curricular structure and competence map of our reference framework do not cover competence and knowledge for designing and implementing hardware solutions. Thus, software and organizational needs concerned by the ACM disciplines are satisfied by our model but not the hardware needs. The application fields and knowledge areas of our reference framework (e.g., infrastructure and security) can be related with the ACM computing areas (e.g., systems infrastructure). The emphasis in developing theoretical aspects (i.e. theory, principles, and innovation) and applied aspects (i.e. assembly, deployment, and configuration) on the computing areas defines the problem space for an ACM computing discipline. Similarly, the competence map and the implementation methodology of the proposed model facilitate curriculum designs to be analyzed according to a specific problem space. This can be done by relating the courses which can be grouped by application area with the PEOs these courses satisfy.

The European Qualifications Framework (EQF) [8] is a reference system to build qualifications readable and understandable across different countries and higher education systems in Europe. The EQF introduces 8 reference levels (e.g., school certificates, doctoral degrees) described in terms of learning outcomes, which are specified in three categories: knowledge, skill, and competence. A learning outcome is defined as 'a statement of what a learner knows, understands and is able to do on completion of a learning process'. Similar to this definition, the PEOs and especially the design-centric ones define what graduates are able to do on each level during their specialized formation. The EQF learning outcomes are general and not linked to any specific discipline. In contrast, the proposed curricula design model defines a set of PEOs specific to the CE discipline and presents a methodology to guide the definition of specific learning goals for a curriculum design.

Traditional engineering curriculums address the lower levels of Boom's taxonomy [9] (knowledge, comprehension, and application) [10]. Other holistic curriculums such as the service design and engineering program (SDE) [1] approach the learning from the higher levels (analysis, synthesis, and evaluation). This identified necessity is considered by the proposed curricula design model approaching the learning in CE from high level competences (e.g., design-centric competences) required to solve problems. In our approach, these high-level competences are integrated in the course design and execution.

Several approaches [11–14] have adopted the CDIO principles to build frameworks to help accelerate efforts in curriculum reform, management, and communication. Similar to these initiatives we have defined a curricula design model to accelerate curricula reform and evolution processes aligned with the continuous change required by the CE programs. Our model offers a project-oriented and systematic curricula design and evaluation process covering all the formation space of graduates.

7. Conclusions

The management of a large CE program requires a structured approach for defining and managing curricula designs. We presented the logic for the adoption of a curricula design and evaluation model for large CE programs design and management. The curricula design model facilitates the design of CE programs to make their emphasis to generate different types of competences involved in the problem life cycle resolution explicit. This paper presents how we used the curricula design model to redesign the CE program at the Universidad de los

Andes in Colombia to create a new design-centric program. This is reflected by the high contribution of design-centric competences to the professional profile. We also presented an assessment method used to evaluate the achievement of design-centric competences. The curricula design model was sent to mostly all CE programs in Colombia looking for an open and broad adoption. The main intention is to ease the analysis and benchmarking of a resulting program design with other CE programs. We expect this model to become a common language for designing programs with high quality and complete goals in both national and international contexts.

Continuous improvement, based on facts such as the results and evidence obtained with the assessment method drive, changes within the curricula design. Thus, it is an undeniable necessity to have a model that allow and eases the adaptation to the ever changing curricula design needs. The proposed curricula design model allows this adaptation by considering a reference framework and an implementation methodology based on competences that are constant to be developed in graduates of CE programs. The resulting curricula designs promote the generation of design-centric competences, facilitating the graduates the adaptation to the changing environment of the profession. It also facilitates and accelerates the efforts for designing and evaluating program designs. This is required by a large number of educational institutions who recognize the need to keep up to date according to the needs imposed by the constant business and ICT evolution.

The curricula design model allows the definition of CE programs in which all the courses are aligned and collaborate to develop a specific professional profile of graduates. This facilitates the impact evaluation on how a change or improvement within a course can affect the integral formation of a graduate, and impose the necessity to align the other courses in response.

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