AN INTEGRATED CURRICULUM, LEARNING ASSESMENT AND PROGRAM EVALUATION MODEL

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ABSTRACT

Electronics Engineering program at Pontificia Universidad Javeriana Bogota - Colombia has been renovated following the guidelines of the CDIO philosophy. Currently, as a result of this process, a five years comprehensive and flexible curriculum is being implemented, based on the guidelines of the twelve CDIO standards. This curriculum reform is part of the strategies of continuous and systematic reflection and improvement of the School of Engineering; it is consistent with competitive schemes of quality with positive impact in the country.
This paper describes tools generated to evaluate the CDIO Program in Electronics engineering. Initially, we describe the process of curricular integration, preliminary objectives for each year, the incorporation of CDIO skills in courses in accordance with the proficiency defined in the curriculum proposal and the gradual progression in learning along the five years of the program. Then, we describe the construction of holistic rubrics which validate the competence level reached by the students at the end of each year. Finally, we propose a model that relates the learning assessment for each course with the holistic rubrics; the latter provide the skills value measure and knowledge achieved by a cohort of students during an established academic term.
The development of holistic rubrics for each year of the program took into account the gradual progression in learning. This gradual structure was proposed in the conception and design of the curricular structure according to Benjamín Bloom's cognitive taxonomy and David R. Krathwohl's affective taxonomy. These assessment strategies are essential for the School of Engineering along the processes of adjusting the curriculum reform, and for the planning of the fourth national certification in 2020 and ABET international accreditation in 2015.

KEYWORDS

Innovations in Teaching, Learning and Assessment, Program Evaluation and Accreditation Standards: 2, 3, 11, 12.

INTRODUCTION

The purpose of the CDIO Initiative is to support the engineering programs for the redesign of the curriculum based on four axes: conceiving, designing, implementing and operating products, systems, and processes. It is by following these guidelines that an education reform has been implemented for the curriculum of the Electronic Engineering undergraduate program at the Pontificia Universidad Javeriana.

First of all, work was undertaken in order to design the curriculum which included the formalization, filtering and weighting of the personal and interpersonal competences as well as those from the CDIO cycle. The result of this stage is a Syllabus that has been adapted to the Electronic Engineering undergraduate program which was developed based on the information generated during the conception stage. Once the competences and the profile of the students were defined, the work started with a reflection process and the reformulation of the disciplinary content by using the backward design technique in order to obtain a new curriculum. The purpose of the curricular design under the backward design technique is to reach an understanding concerning a specific topic of an area, planning and carrying out the teaching process [1]. This methodology includes the identification of the learning objectives and competences that must be reached by a student vis-à-vis a particular topic, including the skills of the adapted Syllabus [2]. As the name of the technique expresses it, reflection starts from the result desired for the end of the course or, in this case, when the program concludes. The curriculum was divided into five education milestones; each one of them coincides with each year of the program. Each year has educational objectives assigned as well as the gradualness that must be achieved by the group of students during each year.

Each course is designed by including the educational objectives, the general activities and the specific rubrics to assess student's learning; this is the type of courses and the experiences that the student will be facing throughout their studies [3]. Each course feeds an evaluation model of the program which includes the results of each cohort in order to verify the objectives reached each year. Said model includes the characterization of the assessment processes pursuant to the national assessment guidelines of the programs and the ABET international accreditation.

CURRICULUM REFLECTION PROCESS

The reform of the Electronic Engineering undergraduate curriculum program derived from a reflection process along which the learning results were reviewed and assessed; that is, them were adapted for the program by the teachers that made up the CDIO group who, in addition, helped to determine the expected levels of competence, for each learning result. Based on the group discussion concerning the body of knowledge and the adaptation of the Syllabus, a general curricular structure was developed taking into account the identification of the duration of a five-year program in order to reach the skills, knowledge and attitudes defined in the previous stages.

A relevant aspect of the new program was the inclusion of integrative projects which become integrated learning experiences leading to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills for the construction of products, processes, and systems [4].

The construction of the curriculum started by articulating the knowledge and skills expected for each academic semester by taking into consideration the educational goals for each year; in addition, the integrative projects become the base of the program [5].

THE NEW ELECTRONIC ENEGINEERING CURRICULUM

A general curricular structure was developed as a result of the curricular reflection process which allows identifying the five years program in order to reach the skills, knowledge, and attitudes defined in the process. In addition, general goals were proposed for each year including the five key dimensions for the program:

- Dimension 1: motivation
- Dimension 2: integration of engineering and basic sciences
- Dimension 3: problem solution
- Dimension 4: integration and application of knowledge and skills
- Dimension 5: autonomy and flexibility

This curricular structure, the basis of the new electronic engineering curriculum, includes 51 articulated courses pursuant to the institutional policies and the disciplinary, integral and flexible guidelines of the program. It has a total of 160 academic credits.

The curriculum is developed based on annual goals, expected knowledges, and disciplinary and general skills, including two components, as shown in table 1. The flexible component is 31.875% of the plan including the elective, the emphasis and the complementary courses. The component of the fundamental core represents 68.125% of the plan including the mathematics, physics, engineering, and institutional lines.

Table 1 - Distribution of the curricular structure in the curriculum

Component		**Number of Courses**	**Number of Credits**	**% of Credits**
Flexible	Elective	6	16	10
	Complementary	3	7	4.375
	Emphasis	8	28	17.5
	Total	17	51	31.875
Fundamental Core	Mathematics	5	15	9.375
	Physics	4	14	8.75
	Engineering	19	67	41.875
	Institutional	6	13	8.125
	Total	34	109	68.125
Total		**51**	**160**	**100**

The integrative projects are considered as key elements. They correspond to 17.5 % of the curriculum and are divided into six courses; four of them correspond to the fundamental core and two of them to the emphasis.

Holistic objectives and general skills

The annual educational goals cover disciplinary and general skills which are expected students to acquire and to apply. These goals will be developed gradually and they include the courses and activities of the curriculum.

It was necessary to identify these skills from the adapted syllabus for each year, in order to define the holistic objectives of the general skills, including the level of competence that will be gradually reached during each semester. As shown in table 2, the general skills at the second level of detail are related to the expected level of competence. This was obtained after averaging together all the weightings from the third syllabus level.

Table 2 - Gradualness of the CDIO Syllabus for the second level of detail

	Sem 1	Sem 2	Sem 3	Sem 4	Sem 5	Sem 6	Sem 7	Sem 8	Sem 9	Sem 10
2.1 ANALYSIS AND SOLUTION OF ENGINEERING PROBLEMS [e]	0,5	1	1,5	2	2	2,5	2,5	3	3	3,5
2.2 EXPERIMENTATION, DISCOVERY OF REALITY AND KNOWLEDGE CONSTRUCTION [b]	0,5	0,5	1	1	1,5	2	2	2,5	2,5	3
2.3 SYSTEMIC THOUGHT	0,5	0,5	1	1	1,5	1,5	2	2	2,5	3
2.4 PERSONAL ATTITUDES AND SKILLS	0,5	1	1,5	2	2	2,5	2,5	3	3,5	4
2.5 PROFESSIONAL ABILITIES AND ATTITUDES	0,5	0,5	1	1,5	1,5	2	2,5	3	3,5	4
3.1 TEAM WORK [d]	0,5	1	1	1,5	1,5	2	2	2,5	2,5	3
3.2 COMMUNICATION [g]	0,5	1	1	1,5	1,5	2	2	2,5	2,5	3
3.3 COMMUNICATION THROUGH FOREIGN LANGUAGES	0,5	0,5	1	1	2	2	2,5	2,5	3	3
4.1 SOCIAL AND EXTERNAL CONTEXT [h]	0,5	1	1	1,5	1,5	2	2	2,5	2,5	3
4.2 ENTREPRENEURIAL AND BUSINESS CONTEXT	0	0,5	0,5	1	1	1,5	1,5	2	2	2,5
4.3 CONCEIVING AND APPLYING ENGINEERING TO SYSTEMS [c]	0,5	0,5	1	1,5	2	2,5	2,5	3	3,5	4
4.4 DESIGN [c]	0,5	0,5	1	1	1	1,5	1,5	2	2,5	3
4.5 IMPLEMENTATION [c]	0,5	0,5	1	1	2	2	2,5	2,5	3	3
4.6 OPERATION [c]	0	0	0	0	0,5	0,5	0,5	0,5	1	1

Table 3 shows the scale used to classify the levels of knowledge and value. The table is presented in Spanish to keep the coherence.

Table 3 – Knowledge and Value Scales

Escala de Conocimiento		**Escala de Valor**	
1	Ser capaz, de reconocer e identificar-------------	1	Tiene conciencia de --------------
2	Ser capaz, de entender (desde construir significados hasta modelos causa - efecto) ----------Corresponde al primer nivel de análisis	2	Está motivado para aceptar el valor de (Considera importante la (el)) --------------
3	Ser capaz, de aplicar e implementar un desarrollo de -------------- Corresponde al segundo nivel de análisis	3	Interioriza el valor del (la) --------------
4	Ser capaz, de integrar conceptos, conocimientos o aplicaciones para el desarrollo de soluciones de -------------- Corresponde al tercer nivel de análisis y el primer nivel de síntesis	4	Actúa consistentemente de acuerdo con la (el) --------------
5	Ser capaz, de liderar, proponer y crear -------------- Corresponde al cuarto nivel de análisis y el segundo nivel de síntesis	5	Puede persuadir a otros sobre la (el) --------------

Table 4 shows an example of the holistic educational objectives that a first-year student must reach at the end of the period for the skill 2.1 of the CDIO Syllabus, with ‘1’ level of competence.

Table 4 - Holistic educational objectives for skill 2.1 in year 1

At the end of the first year, the student must be able to:
2.1 Analysis and solution of engineering problems [e]
• Identify needs or problematic situations. • Describe problems and know the data and the evidence that give rise to it. • Establish the relationship between the problem and physical phenomena as well as with mathematical representations. • Define preliminary solutions, from different points of view, by describing the functional behavior of the solution.

The holistic objectives and the general skills are necessary in order to integrate subjects, design and implement courses, as well as to carry out the evaluation of the program.

CONCEPTION, DESIGN AND IMPLEMENTATION OF THE COURSES

We used the Backward Design technique for designing and implementing the courses. Therefore, we designed the disciplinary content of each course, the general skills, and the levels of competence (both for content and skills) depending on the place they have in the curriculum. They are the necessary input in order to define the learning outcomes of the course, the evidence of success, the learning and assessment activities, as well as the space and time-related resources.

The learning outcomes may be defined as a description that includes the concepts and principles that the students will get to know at the end of the course; the skills, processes and procedures they can put into practice [6]; and the attitudes and attributes that the students will emphasize or value. On the other hand, the evidence of success is the information that supports the fact that an educational result has been reached. It shall be assessed by using specific rubrics derived from the learning and/or assessment activities; in other words, through the learning assessment [7].

The program of a course includes the educational results and the levels of competence that must be reached. In addition, it is duty of the teacher proposing the activities and the rubrics that could evidence that the goals of the course were reached [8]. The specific rubrics of the course must be aligned with the processes of the program. The following section describes this process in detail and its direct relationship with the goals for the year, the educational results, and the rubrics of the course.

Table 5 shows the example of the integration of the Digital Systems course from the fourth semester of the program. It also shows the disciplinary content, the general skills and attributes vis-à-vis the level of competence expected at the end of the course. Subsequently, some educational results are described. They integrate topics, skills and attitudes as well as the activity aimed at learning them. To conclude, the assessment rubrics for the activity are detailed, considering some criteria and the performance scales for the learning assessment.

Table 5 - An example of the integration in the Digital Systems course

Disciplinary Content		General Skills and Attributes	
Topic	Level of competence	Skill / Attribute	Level of competence
Designing digital systems	**3**	Modelling the problem	2
Designing specifications for a digital system	**3**	Solutions and recommendations	2
Description of the behavior of the digital system in time by establishing the relationship between input vs output	**3**	Perseverance and flexibility	2
Generation of specifications of the system in time by detailing the initial specifications of the design	**3**	Creative thinking	1,5
Description of the behavior of each block in time	**3**	Critical thinking	1,5
Specifications of each block in time	**3**	Communication strategies	1
Combination and Sequences	**3**	Communication structure	1
Status machines	**3**	Stages and approaches of the design process	1

Learning Outcomes	Activity
An example of the integration of topics and skills	Preliminary specifications and requirements
Illustrating time diagrams so others can understand, including concepts related to the sequence of events, signals grouping, coding, tolerances, orders of magnitude, standardization, uncertainty, periodicity, pulse width, duration, and the activity of the signal, diagram longitude, notation, presentation, and formality. Describing the temporary behavior of one system in writing. Assessing the feasibility of the behavior in time based on the requirements. Interpreting time diagrams based on standardized notations, diagrams and common signals, and using the oral description of the behavior of the system in time based on the sequence of the events. Describing, through time diagrams, the information that allows validating the problem requirements (client) by identifying the I/O with its characteristics, using notation in an adequate manner, identifying the signs, their frequency, activity, and useful cycle. Interpreting time diagrams under simulation conditions and with instruments as diagnostic tools for the system vis-à-vis the validation and verification processes. Using the analyzer of logical states through a	A circuit is needed so the Gray conversion is carried out in which the input data appear in a consecutive sequential manner per clock period through the x input line. Simultaneously, the z output line shows the datum with its corresponding Gray conversion. A starting signal will show that a valid data sequence starts in the following clock period through the x input line. There are no clock delay periods between the input and the output of the converted data. The system is restarted each time the external starting signal is at zero. State the general inputs and outputs of the system by describing its characteristics and behavior. Describe the general functioning of the system. Illustrate the time diagram representing the behavior of the system vis-à-vis the inputs and outputs. Prepare a block diagram by indicating the interconnection signals between the blocks. State the input and output interphase of each block and describe its characteristics and behavior. Illustrate the time diagram representing the behavior of the system showing the input, output, and interconnection signals between the blocks. State the general inputs and outputs of the system by describing their characteristics and behaviors. Describe the general functioning of the system vis-à-vis the inputs and outputs. Prepare a block diagram by

configuration pursuant to the measurement thus allowing ensuring the maximum resolution, precision, and accuracy of the measurements.	indicating the interconnection signs between the blocks.	
Assessment Rubrics for the Activity		
Assessment criteria	Performance scales	
Rubric 1		
The description of the general input and output signals includes concepts of periodicity, synchronism with the clock of the system to be designed, pulse width, duration, and activity of the signal.	***Performance criterion that exceeds the expectation***	The description of the starting signal, as a probable non simultaneous input vis-à-vis the clock, includes an analysis of the time restrictions (pulse width) to be detected by the system.
	Expected performance criterion	The description of the general input and output signals of the system includes concepts of periodicity, synchronism with the clock of the system to be designed, pulse width, duration, and activation of the signal.
	Performance simple criterion	Identifies and differentiates input and output signals in the system.
	Performance expected criterion, with help	Help is required in order to identify some of the characteristics of the input and output signals.
	Unsuccessful - even with help	It does not identify the inputs or outputs of the system.
Rubric 2		
The time diagram of each one of the signals meets the requirements of periodicity, pulse width, duration, signal activation, notation, and presentation.	***Performance criterion that exceeds the expectation***	The time diagram has such a coverage that shows the cases that are necessary in order to describe the system.
	Expected performance criterion	The time diagram of each one of the signals meets the requirements of periodicity, pulse width, duration, activation of the signal, and presentation.
	Performance basic criterion	The time diagram shows some signals in a correct manner but they do not evidence

		coherence between themselves.
	Performance expected criterion, with help	Help is required in order to draw some of the signals.
	Unsuccessful, even with help	There is no coherence between the signals and the characteristics are erroneous.

ASSESSMENT MODEL OF THE PROGRAM

The criteria for the assessment of the program are based on questions that inquire about the behavior of each area for each particular standard; they are suggested by the CDIO consortium. In brief, a program is deemed successful if it can evidence that the components described in the standards reached the objectives and goals proposed. The Electronic Engineering program has applied the evaluation of the program by verifying the success rubrics for each one of the standards since 2010. As per the implementation and operation of the new Electronic Engineering program, the fulfillment of the quality criteria for the curriculum, as established in the CDIO standards, is assessed by collecting the indicators in order to evidence that the objectives of the program have been reached in each academic period. The plan of the courses described through educational results and rubrics for the assessment of learning allows feeding the general assessment system and getting a systemic perspective concerning the advance of the cohorts and the effectiveness of the curriculum.

Assessment of the curriculum

The general assessment system is fed through the educational results and the rubrics of the courses to have a systemic perspective of the goals reached by the cohorts and the effectiveness of the curriculum.

The corresponding holistic rubrics were developed for all the educational holistic objectives at the second level of detail. The Table 6 shows, as an example, the assessment rubrics used in the follow up process of the objectives described in Table 3, for skills 2.1 of the CDIO Syllabus with level ‘1’ of competence.

Table 6 - Holistic assessment rubrics for objectives 2.1 in year 1

Assessment rubrics for the objectives described in Table w
2.1 ANALYSIS AND SOLUTION OF ENGINEERING PROBLEMS [e]

- Identifies needs or problematic situations; describes problems and establishes the relationship between the problem and physical phenomena as well as with mathematical representations.
- Knows the data and evidence that give rise to the problem.
- Defines preliminary solutions, from different points of view, by describing the functional behavior of the solution.

Each holistic objective for the year has a related rubric, so all the skills or attributes of the CDIO Syllabus shall be gradually assessed for each cohort. The courses that belong to one year are responsible for different skills, attributes, and levels of competence. In this sense, the teachers must teach and evaluate all the elements included therein. Then, pursuant to learning assessment of the students, the teacher shall be in charge of assessing, through holistic rubrics, the level of competence of the group, vis-à-vis each objective for the year he is responsible for by collecting the activities, learning assessment rubrics, and evidence of the work supporting said evaluation.

A holistic rubric shall include an assessment criterion directly related to the annual objectives and the performance levels of the cohort. As per the evaluation of the program, said levels are the equivalent to the number of students that, pursuant to the opinion of the teachers, have reached that competence. Table 7 shows an example of objectives for the year along with the corresponding assessment rubrics and the gradualness through the program. The assessment of each skill and the contrast vis-à-vis of the achievements for every year, shall allow providing feedback to the program and developing corrective measures during the following academic period.

Table 7 - Gradualness in the objectives of the year and the holistic rubrics

Skill	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Formulation and identification of problems – Modelling the problem	**Level of competence**				
	1	**2**	**2.5**	**3**	**3.5**
Objectives	Identifying needs or problematic situations within specific contexts. Describing problems. Establishing relationships between the problems with the physical phenomena and mathematical representations.	Explaining the cause-effect relationships and the symptoms of a problem in order to define it. Applying physical models and mathematical representations in order to define a problem. Using technological tools in order to define a problem.	Defining conceptual, qualitative, and quantitative models of the problem.	Stating an action plan (or several action plans) pursuant to the conceptual, qualitative, and quantitative models of the problem. Using simulations, the numerical analysis, and experiments in order to determine them.	Choosing and carrying out an action plan pursuant to the conceptual, qualitative, and quantitative models of the problem. Using assumptions in order to simplify complex environments and systems.
Rubrics	**Assessment Criteria**				

	Identifying needs or problematic situations. Describing problems. Establishing the relationship between the problem and the physical phenomena and mathematical representations.	Explaining the cause-effect relationships and the symptoms of a problem in order to define it. Applying physical models and mathematical representations in order to define a problem. Using technological tools in order to define a problem. .	Defining conceptual, qualitative and quantitative models of the problem.	Stating an action plan (or several action plans) pursuant to the conceptual, qualitative, and quantitative models of the problem. Using simulations, the numerical analysis, and experiments in order to determine them.	Choosing and carrying out an action plan pursuant to the conceptual, qualitative, and quantitative models of the problem. Using assumptions in order to simplify complex environments and systems.
	Performance scales pursuant to the learning assessment in the courses				
	Performance criterion that exceeds the expectation		>75% of the cohort		
	Expected performance criterion		Between 60% and 74% (sic)		
	Simple performance criterion		Between 40% and 59% of the cohort		
	Low performance criterion		Between 20% and 39% of the cohort		
	Unsuccessful		Between 0% and 19% of the cohort		

The forms for the evaluation of the course shall allow developing a thorough analysis of each cohort in one semester in order to validate that the objectives for the year have been reached; so that, the teaching-learning processes must be perfected as well as the assessment processes of the courses. The starting point for the analysis of each academic period is that although the students face the same skills and attributes in different courses, their teaching and assessment come from different sources so that, as per a statistical analysis, they behave as independent measurements and the central tendency measurements. Those measurements can be the average of the students at a performance level for a specific rubric, or the geometric mean to identify maximum and minimum levels vis-à-vis the behavior, may be shown as descriptors. In addition, the correlations between the data obtained will be analyzed in order to determine the association between variables and the multivariate analysis in order to establish the relationship between skills and attributes, as well as their learning and evaluation methods.

CONCLUSIONS

Questions about engineering education and the related learning processes have been presented in the reflection of the Electronics Department at the University for several years. The reflection concentrated its effort in the review and adoption of new and more efficient ways to achieve a better process of learning by students. This process found the possibility of implementing new practices and testing them in the courses of several areas. Faculty modified classroom methodology in some of the courses and leaned towards a methodology in which active learning, learning through projects, work in group, and others are prioritized. In this model teacher is a guide, not the center of the course process. The experiences in these courses and the results obtained by the students motivated us to review the work of other educational organizations, finding some similarity between our work and the proposals of the CDIO initiative.

Previous approaches motivated us to learn more about the CDIO Initiative, and to be part of it; therefore we began a reflection process about our program. This reflection has resulted in a curriculum reform with huge implications, not only at the level of the program and faculty, but also at the School of Engineering and the University levels.

The curricular reflection of the Electronic Engineering program, within the framework of the CDIO initiative, has had as its basis, the articulation with the Mission, so its guidelines are clearly reflected on the objectives of the problem, as well as the concepts of disciplinary flexibility and the work with other knowledge domains as basic sciences, philosophy, political sciences, and theology; particularly, the integrative projects proposed include working with different disciplines. The new curriculum is designed with a demanding academic load, lower than the current one, which will allow effective learning processes during the time periods set for each course. One of the axes of the new reform is to keep the motivation of the students which would influence their academic performance and, therefore, would reduce their permanence and drop-out. The general objective of the curriculum, as per keeping the motivation of the students, shall make it possible to continue working in order to decrease the drop-out rate. This rate and the quality of the student´s work are measures of both student´s motivation and the program´s success. In addition, the new curriculum keeps the model of elective courses; flexibility is reflected on the emphasis area offered at the end of the program, as well as on the three integrative projects which are multidisciplinary in nature.

The curriculum reform was accompanied by the conception and design of a model for the learning assessment and program evaluation based on rubrics. These rubrics were generated from the learning objectives for each year of the plan of studies and the integration of CDIO Syllabus competences. CDIO skills are valued every year through the courses headings. On the other hand, the School of Engineering has planned to start the ABET international accreditation process for the four undergraduate programs. Said project implies a structure that synchronizes the evaluation processes of the current Electronic Engineering program and the new curriculum. It was necessary to undertake a coherence analysis between some elements of the CDIO initiative and international accreditation guidelines in order to carry out joint CDIO-ABET processes.

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