DISCOVERING PROFICIENCY LEVELS FOR CDIO SYLLABUS TOPICS THROUGH STAKEHOLDER DIFFERENTIATION

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ABSTRACT

Engineering education is based on articulated goals and student learning outcomes developed through curriculum programs. The first task of turning the CDIO vision into a curriculum program is to develop an understanding of abilities needed by contemporary engineers. Such abilities are discovered from stakeholders who formalize the knowledge, skills, and attitudes expected from engineering graduates. Engineering education has four key stakeholder groups: students, industry, university faculty, and society. The vision of engineers the society needs varies between groups of stakeholders. For instance, industry and university faculty may disagree about the levels of proficiency the engineers may achieve regarding a particular CDIO syllabus topic, e.g. Knowledge of marketing principles. This paper presents an approach to generate unified syllabuses departing from surveys conducted to several stakeholder groups. The approach considers, for every CDIO syllabus topic, a specific proficiency level and an impact factor. The proficiency level is a specific value assigned by each stakeholder to each topic. The impact factor is a value that is associated to each stakeholder group according to his experience and proficiency level on a particular topic. The approach has a direct application for practical curricula committees and is supported by an open source tool.

KEYWORDS

Curriculum design, stakeholder differentiation, proficiency level discovery.

INTRODUCTION

Engineering education is based on articulated goals and student learning outcomes developed through curriculum programs. The first task of turning the CDIO vision into a curriculum program is to develop an understanding of abilities needed by contemporary engineers. In order to determine the level of proficiency that is expected in a graduating engineer, different types of studies are usually conducted for discovering stakeholder expectations. These studies are based on techniques such as interviews, focus groups and surveys. They have as objectives 1) to capture the inputs and opinions of all the potential stakeholders of the educational program, and 2) encourage consensus building based on both individual viewpoints and collective wisdom.

Engineering education has a large number of stakeholder communities who might be included in the survey and consensus process. External and internal stakeholders must be involved: alumni groups of various ages, industry representatives, peers at other universities, standing and *ad hoc* advisory boards, faculty in other departments at the university, current undergraduate students and other members of the society. Given the growing need of engineers with multidisciplinary viewpoints and diverse depth of knowledge in particular industry and academic sectors, the stakeholder body is becoming increasingly diverse. Involved stakeholders now vary from practical engineers to PhD researchers; and they have their own perceptions, stereotypes, epistemologies and ontologies. This trend increases the number of trade-offs between required levels of proficiency the engineers may achieve regarding a particular CDIO syllabus topic, e.g. Knowledge of marketing principles.

Various authors (e.g. [1,2,3]) have explored approaches to design surveys and rubrics used on several techniques for collecting data from stakeholders; they have also proposed mechanisms to study and compile information. As far as the authors know, these studies agree in the need of finding consensus between stakeholders in regard to the proficiency levels required for syllabus topics. If consensus is not achieved, it is aimed to perform closer reading of qualitative inputs and then make choices that align with the context and local program goals. A challenge is then assigned to curriculum committees who wonder: how to make choices regarding the proficiency levels required for syllabus topics when consensus between stakeholders is not achieved? How to align the context and local program goals having into account the valuable experience and opinions documented from stakeholders?

This paper presents an approach to generate unified syllabuses departing from surveys conducted to several stakeholder groups. The approach considers divergences between stakeholder groups' opinions and a lack of consensus regarding proficiency level required for CDIO syllabus topics. Such divergences are treated as natural and expected, and are used to obtain qualitative outputs based on characterization of stakeholders groups and results of conducted surveys. The authors propose to explicitly value and weigh the experience of every stakeholder group in their practice field of action, and present an open source tool designed to support the proposed approach. The paper is organized as follows. Section 2 reviews previous contributions about discovering and valuing stakeholder expectations. Section 3 presents the process that supports the application of the approach. Section 4 introduces tool support for the approach. Section 5 shares a case study, the methodology the authors followed when applying the approach, and summarizes discussion. Section 7 concludes.

DISCOVERING AND VALUING STAKEHOLDER EXPECTATIONS

Researchers and practitioners agree about the importance of early involvement of committed, informed, and representative stakeholders in order to ensure that the context of contemporary engineers is properly understood during a curriculum (re)design; they also agree in the need to process and analyze data recovered from surveys conducted to involved stakeholders (e.g. [4,5,6]). With the objective of assuring that stakeholders provide reliable information, some methodologies in several fields have been proposed remarking the importance of 1) making a correct identification of stakeholders, 2) developing an appropriate profile, and 3) establishing mechanisms for participation in the project (e.g. [1,7,8]). For instance, Schmeer [7,8], suggests that the profile definition of an stakeholder should include: 1) motivation for being in the project, 2) perceived expectations and goals in relation to the project, 3) level of importance for the success of the project, 4) potential negative impact on the project, 5) level of influence over the project for decision-making, 6) intention to participate according to the project design, and 7) intended use of the project or the project results.

Some authors present their experience in the use of strategies to identify and characterize stakeholders. For example in [9], the authors use personas to guide needs analysis and curriculum design of an engineering program. The paper describes the stakeholder's needs analysis phases of the project, where current occupational roles for engineers were mapped out in order to find what knowledge skills and attributes are necessary to work in this field. Nevertheless, as far as the authors have studied, there is a lack of documented studies and experiences that face the problem of discovering required proficiency levels of graduate engineers, recognizing and valuing the differentiation of stakeholders involved in the discovery of required profile of young engineers.

DISCOVERING PROFICIENCY LEVELS FOR CDIO SYLLABUS TOPICS

In this section is presented a repeatable process in order to define and document the approach to generate unified syllabuses departing from surveys conducted to several groups of stakeholders. The process considers activities to have into account the valuable experience and documented opinions of stakeholders, and is accompanied of a usage scenario to illustrate the approach step by step. Figure 1 summarizes the process by presenting the activities involved. Three stages are designed; the first one involves activities for setting the context for the survey; the second one is focus on the assessment itself; the third one concludes and summarizes final results.

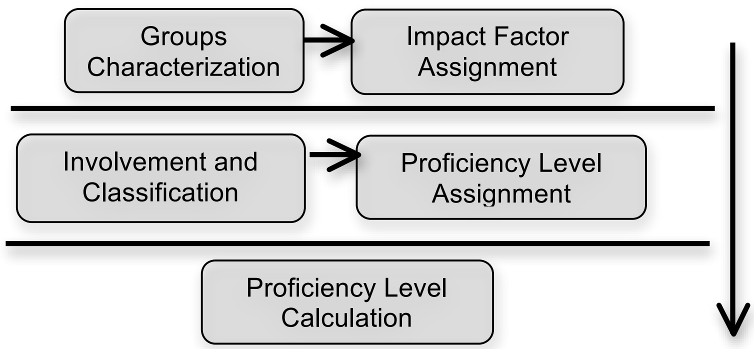

Figure 1. Repeatable process for discovering proficiency levels

Groups Characterization

Curriculum committees may identify several groups of stakeholders; such groups share common interests but differentiate to each other in regard to requirements for graduating engineers. Examples of groups are external or internal stakeholders, academic or industrial stakeholders, among others. Groups must be defined according to particular interests of every institution. For instance, it can be desirable for Universities under development, with a limited number of alumni, to consider alumni as an only group. Universities with a big number of alumni can decide to classify them into several groups, for instance having into account the industrial sector where they have expertise, *e.g.* health, finances or education between others. This activity is performed before selecting the persons that will act as stakeholders. It is important to remark the need of (1) defining a profile before selecting the people who participate as stakeholder, and (2) to make explicit the characteristics accompanying such profile.

Due to the limited extension of this writing, lets define a usage scenario where only three groups with generic characteristics are identified:

1. *Students.* They are current students with at least two years as part of the program.
2. *Alumni.* They are engineers with at least three years of work experience after graduating from the University where the reform being conducted.
3. *Industry.* They are engineers with at least ten years of work experience after graduating, and hold a management position at an enterprise in the engineering industry.

Impact Factor Assignment

Given the sensible differences between groups of stakeholders in appreciations of importance of a syllabus topic, the approach considers defining a specific impact factor for every identified stakeholder group in relation to each CDIO syllabus topic (the authors suggest remaining at level three of the CDIO syllabus, excluding the topic 1.1, which must be treated at level four with the objective of detailing disciplinary knowledge). The impact factor is assigned according to the relative experience and proficiency level of each group on a particular topic. Thus, it is possible to assign a bigger impact factor to stakeholder groups with more experience in regard to a syllabus topic. For instance, it is possible to assign a bigger impact factor to *Industry* when talking about *Multidisciplinary Design* than the one assigned to *Student*. The curriculum committee, which is conformed by faculty and stakeholders of every group, is the responsible of assigning impact factors. A common agreement must be achieved before starting the survey process. Table 1 presents an example of the assignment of the impact factor for the three stakeholder groups previously introduced as part of the usage scenario, in relation to three CDIO syllabus topics.

Table 1. Example of impact factor associated to stakeholders' groups

CDIO Syllabus\Stakeholders Group	Student	Alumni	Industry	Total
4.3.1 Setting System Goals and Requirements	30%	30%	40%	100%
4.4.5 Multidisciplinary Design	10%	30%	60%	100%
4.5.3 Software Implementing Process	30%	40%	30%	100%

The impact factors in Table 1 must satisfy the restriction imposed in Equation (1):

$$\sum_{j=1}^{J} w_{i,j} = 1 \quad (\forall i \in I) \quad (1)$$

Where: ***J***={1,2,3,....,*J*} is the set of stakeholders groups.
I={1,2,3,....,*I*} is the set of CDIO syllabus topics considered.
$w_{i,j}$ is the impact factor for *j-th* stakeholder group in the *i-th* CDIO syllabus topic.

It is possible to assign the same value for every pair -CDIO Syllabus Topic, stakeholder group- when all them are considered as equal regarding experience and proficiency level; it is also possible to assign the lowest impact factor –zero- when a stakeholder group is considered as irrelevant in the survey of the level of proficiency of a particular topic.

Involvement and Classification

Once the group characterization is ready and impact factors have been assigned, people accomplishing the defined profiles are engaged to the survey process. Since the characterization of groups does not consider creating exclusive groups, the approach considers the case where a stakeholder may be part of several groups. Table 2.a presents an example as part of the usage scenario created to illustrate the approach. Please note that stakeholder 3 (S 3) and stakeholder 4 (S 4) are labeled as both *Alumni* and *Industry.*

Table 2.

(a) Example of stakeholder groups

Stakeholder\ Stakeholder Group	Student	Alumni	Industry
S 1	X		
S 2		X	
S 3		X	X
S 4		X	X

(b) MIT activity based proficiency scale

1. To have experienced or been exposed to
2. To be able participate in and contribute to
3. To be able to understand and explain
4. To be skilled in the practice or implementation of
5. To be able to lead or innovate in

Proficiency Level Assignment

The approach considers conducting a survey questionnaire that ask questions on the desired levels of proficiency graduate engineers must have. Only quantitative responses are solicited. In order to insure reasonable consistency of quantitative responses, the MIT activity based proficiency scale is used (See Table 2.b [10]). This scale asks the respondent to rate the expected level of proficiency of a graduating engineer on a five point activity based scale, which is based on "activities", and ranges from "To have experienced or been exposed to" at level 1, to "To be able to lead or innovate in" at level 5. The authors added one item to the scale: "To have no experience or been exposed to". Table 3 presents an example as part of the usage scenario created to illustrate the approach; *St* stand for *Student*, *Al* for *Alumni* and *In* for *Industry*.

Table 3. Example of proficiency levels expected by stakeholders

CDIO Syllabus\Stakeholder	S 1 (St)	S 2 (Al)	S 3 (Al,In)	S 4 (Al,In)
4.3.1 Setting System Goals and Requirements	2	3	3	5
4.4.5 Multidisciplinary Design	2	3	4	5
4.5.3 Software Implementing Process	3	4	3	4

Proficiency Level Calculation

Quantitative responses of involved stakeholders and impact factors assigned to the pairs -CDIO Syllabus Topic, stakeholder group- are used to guide the determination of the expected levels of proficiency of students at graduation. The calculation process considers for every CDIO syllabus topic (*first*) obtaining the proficiency level average assigned for every stakeholder group, and (*second*) summarize the product of averages times the impact factor assigned to each stakeholder group. The result is considered as the final proficiency level expected for every topic.

Table 4 presents the result in the context of the usage scenario created to illustrate the approach. As example, let's examine the data related to the CDIO syllabus topic 4.4.5. First, for every stakeholder group the average is computed. Thus, it is 2 for *Student,* 4 for *Alumni*, and 4,5 for *Industry*. One decimal is used in order to maintain precision of the computation. Second, the final proficiency levels are computed using the just calculated average and the previously assigned impact factor. Note that one decimal is still used in order to maintain precision of other computations; however, at this point the approach considers rounding the obtained data. Thus, for example, for our computed CDIO Syllabus Topic 4.4.5, the proficiency level will be four (4). It means, students have *To be skilled in the practice or implementation of Multidisciplinary Design.* The approach also considers computing the proficiency level of CDIO syllabus topics at level two. This is achieved by computing the average of all the related topics at level three.

Table 4. Example of resulting proficiency levels for the usage scenario

CDIO Syllabus\Stakeholder Group	Student	Alumni	Industry	Total
4.3.1 Setting System Goals and Requirements	2	3,6 (3+3+5)/3	4 (3+5)/2	3,3 (2x30%)+(3,6x30%)+(4x40%)
4.4.5 Multidisciplinary Design	2	4 (3+4+5)/3	4,5 (4+5)/2	4,1 (2x10%)+(4x30%)+(4,5x60%)
4.5.3 Software Implementing Process	3	3,6 (4+3+4)/3	3,5 (3+4)/2	3,4 (3x30%)+(3,6x40%)+(3,5x30%)

Equation (2) permits the calculation of the proficiency levels of *i-th* CDIO Syllabus Topic:

$$CST_i = \sum_{j=1}^{J} \overline{PL}_{i,j}.w_{i,j} \quad (\forall i \in I) \quad (2)$$

Where:
CST_i is the *i-th* CDIO syllabus topic and
$\overline{PL}_{i,j}$ is the proficiency level average of *i - th* CDIO syllabus topic by *j – th* stakeholders group. The proficiency level average can be calculated as stated by Equation (3).

$$\overline{PL}_{i,j} = \frac{1}{N}\sum_{k=1}^{N} PLE_{i,j,k} \quad (\forall\, i, j) \quad (3)$$

Where: **N** = {1,2,3,.....*N*} is the set of stakeholders involved in evaluation of *i-th* CDIO syllabus topic and $PLE_{i,j,k}$ is the proficiency level evaluation of *i-th* CDIO syllabus topic by *k-th* stakeholder of *j-th* stakeholders group.

OPEN SOURCE TOOL SUPPORT

Due to the volume of the dataset that must be collected, classified and computed, the approach requires tool support in order to be usable. The authors of this paper developed two alternatives of tool support. On the one hand, the authors developed several spreadsheets that serve as templates for collecting information of stakeholders, stakeholder groups, impact factors and surveys. On the other hand, the authors developed a software system that supports all the activities of the process described in previous sections; the software system promotes availability, concurrency, scalability, distribution and transactionability. The tool support and user manuals are developed under an open source license; they are available for the reader in a GitHub repository [11]. Figure 2 presents an example of a survey form developed as a spreadsheet. By using the spreadsheet, each stakeholder associates a proficiency level for every topic supported by a drop down list. The spreadsheet also allows displaying the level 4 of the CDIO syllabus with the objective of helping stakeholders understand the topic at level 3.

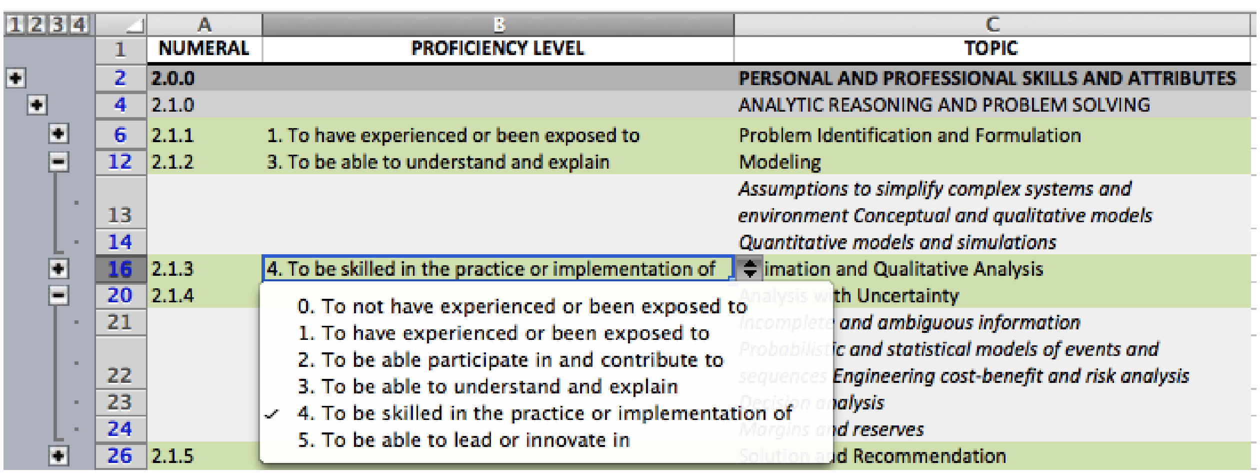

Figure 2. Tool support developed as a spreadsheet for a survey form.

CASE STUDY AND DISCUSSION

The authors of this paper, along with a curriculum committee, designed in 2010 a curriculum based on CDIO principles for the program of Systems Engineering for the freshman Class of

2011 and later. The curriculum design process followed a top-down strategy. Starting from the macro-curriculum design, the process began identifying the required set of learning outcomes the curriculum was going to target; learning outcomes were discovered by using the complete CDIO syllabus topics. Decisions about when and what learning outcomes are introduced, taught and applied were taken by the curriculum committee after defining the curriculum requirements, which came from stakeholder groups.

Regarding the methodology the authors used in 2010 for discovering and valuing the concerns of the involved stakeholders, being the first exercise of curriculum design performed under CDIO principles at their University, the authors did not follow the complete approach presented in this writing. Groups were characterized in *Faculty*, *Students*, *Alumni* and *Industry*, stakeholders were surveyed and data analyzed. A total of 12 stakeholders were surveyed, though some stakeholders were accounted for in more than one group. The authors, however, did not have into account the experience and proficiency level of stakeholders in particular syllabus topics. Qualitative analysis was performed and conclusions were obtained mainly remarking on arguments from the faculty group.

In the iterative process of curriculum reform, at the end of 2012, the curriculum committee revised the conclusions obtained in 2010. The previous surveys were studied, stakeholders where classified by groups and impact factors were assigned to every group and relation to CDIO syllabus topics in order to follow the complete approach presented in this article (see summary of the approach in Figure 1). The impact factors were assigned in consensus with the curriculum committee, which included representative stakeholders from every group. Table 5 presents an extract of assigned impact factors.

Table 5. Impact factors assigned to stakeholder groups

CDIO Syllabus\Stakeholders Group		Faculty	Student	Alumni	Industry	Total
2.1.2	Modeling	40%	20%	20%	20%	100%
2.1.4	Analysis with Uncertainty	10%	10%	70%	10%	100%
2.4.2	Perseverance, Urgency and Will to Deliver, Resourcefulness and Flexibility	15%	15%	40%	30%	100%
3.2.1	Communications Strategy	10%	5%	45%	40%	100%
3.2.9	Advocacy	40%	20%	20%	20%	100%
3.3.1	Communications in English	20%	20%	40%	20%	100%
4.1.1	Roles and Responsibility of Engineers	70%	10%	10%	10%	100%
4.3.1	Understanding Needs and Setting Goals	30%	10%	30%	30%	100%
4.5.2	Hardware Manufacturing Process	20%	20%	30%	30%	100%
4.6.4	System Improvement and Evolution	20%	20%	30%	30%	100%

Table 6 presents a comparison between results obtained in 2010 and results obtained using the presented approach that considers the use of impact factors. Differences are notable and claim to take special attention to stakeholder groups classification. For example, CDIO syllabus topic 2.1.2 (Modeling) obtained a resulting proficiency level of 4 (To be skilled in the practice or implementation of) without the use of impact factors defined for the stakeholder groups. Applying the proposed approach to calculate the resulting proficiency level, with the impact factors from Table 5, topic 2.1.2 now acquires a proficiency level of 3 (To be able to understand and explain). This is due to the higher impact factor established for the Faculty stakeholder group for that specific syllabus topic (See Table 5). A similar result can be observed in the final proficiency levels for the other topics presented. All the information collected from the stakeholders in the survey as well as the consolidated results with and without impact factors can be found in the GitHub repository [11].

In order to summarize discussion about obtained results, three variables impact the results and must be considered in future work: 1) the number of stakeholders in each group, 2) the commitment and representativeness of stakeholders, and 3) the strategy to assign impact factors. Regarding the first and second point, the authors consider important to involve as much as possible stakeholders; however, it is more important to engage committed and representative people. A big number of stakeholders without real interest in the curriculum reform only add noise to the final results. Regarding the third point, the authors consider important to conduct statistical analysis in order to assign impact factors and summarize results of surveys. The current strategy, which suggest to compute the average of data provided by stakeholders, is susceptible of being improved; however, the scope of this writing do not consider to expose recommendations regarding this variable. Finally, as for all curriculum reform, a deeper analysis is required in order to validate the results of acceptation in industry of young engineers with particular developed competences. Even when qualitative results can be obtained, it is mandatory to measure the real impact of the curriculum change when students end the Program and get involved in the real industry.

Table 6. Comparison of results after using the approach

CDIO Syllabus\Stakeholders Group	Fac Avg	Stu Avg	Ind Avg	Alu Avg	Rounded Total without Impact Factors	Rounded Total with Impact Factors
2.1.2 Modeling	3.4	3.5	3.5	3.67	4	3
2.1.4 Analysis with Uncertainty	1.6	2.25	3	2.33	2	3
2.4.2 Perseverance, Urgency and Will to Deliver, Resourcefulness and Flexibility	3	2.75	3.75	4	3	4
3.2.1 Communications Strategy	2.4	1.75	4	3.67	3	4
3.2.9 Advocacy	2	2.75	3	2.67	3	2
3.3.1 Communications in English	3.4	2	4.25	4	3	4
4.1.1 Roles and Responsibility of Engineers	2.2	1.5	3.5	3.33	3	2
4.3.1 Understanding Needs and Setting Goals	3.8	2.75	3.5	3.67	3	4
4.5.2 Hardware Manufacturing Process	0.2	1.5	2.75	1.33	1	2
4.6.4 System Improvement and Evolution	2	3.75	4.25	3.67	3	4

CONCLUSIONS

This paper presented an approach to generate unified syllabuses i) departing from surveys conducted to grouped stakeholders, ii) considering divergences between stakeholder groups opinions and a lack of consensus regarding proficiency level required for syllabus topics, and iii) valuing and weighing every stakeholder experience and proficiency level in their field of action. The authors introduced a systematic process, illustrated by a usage scenario, that includes activities for the cycle of defining stakeholders profiles, selecting stakeholders, surveying them and computing data for obtaining unified syllabuses based on the CDIO syllabus topics and the MIT activity based proficiency scale. In addition to the process, open source tool support was introduced with the objective of making the approach usable in real practice.

By means of a case study, the authors discussed the differences found between results of traditional surveys that do not take into account the approach and results obtained by following the suggested process. The resulting data evidence a big gap, calling to a deeper analysis that focus in quality factors of the stakeholders sample used to conduct the assessments, and the proficiency levels of stakeholders regarding the CDIO syllabus topics. As future work the authors stand the importance of implementing the approach in several curriculum reform process, and perform data analysis that conduct to findings to improve surveys processes. The authors also emphasize in the importance of developing tool support that help curricula committees during the curricula reform process and the posterior data analysis of results; quantitative techniques are also called to be proposed to measure the effectiveness of curriculum changes.

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