EVALUATION OF ALTERNATIVES TO IMPLEMENT A CDIO PROGRAM USING GMA

Alexander Vera-Tasama, Jaiber Cardona and Jorge Ivan Marin-Hurtado

Electronic Engineering Program, Universidad del Quindío, Armenia-Quindío, Colombia

ABSTRACT

The implementation of a CDIO program depends on the context where it is located as well as the institutional mission and program goals. Additionally, it is essential to take into account relevant administrative issues and strategical aspects for an effective adoption of the CDIO standards. In order to select the most appropriate strategies for the implementation of a CDIO program, it is necessary to consider different dimensions that turn this task out a complex problem. Under this consideration, this article applies the general morphological analysis (GMA) for the definition of the implementation strategies for a CDIO program. The results were contextualized to the Electronic Engineering Program at the Universidad del Quindío, Colombia, analyzing four relevant cases: the current state, the desired state, the state with institutional elements, and the state with program elements. The proposed cases can be adapted to other institutions seeking to implement a CDIO program with similar features.

KEYWORDS

CDIO Implementation, Complex Problems, General Morphological Analysis (GMA), Administrative Structure, Standards: 7, 8, 9, 10.

INTRODUCTION

The implementation of a CDIO academic program must consider different elements such as curricular design, pedagogical strategies for the development and evaluation of disciplinary, personal, interpersonal and professional skills, and training of the faculty, among others. Given the importance of the adoption of these academic and administrative elements to achieve the educational needs in a global context, it is imperative to clarify the dynamics between their components, aligned with the missional goals of both the institution and the program.

Starting from an integrated curriculum already designed, it is important to consider the reference points for the insertion of the elements mentioned above, specifically curricular administration, human resources and classroom strategies. Since multiple parameters are involved in this process, which depends on the context, the curricular implementation behaves as a complex or wicked problem, a term coined by Horst Rittel in the 70s (Rittel &

Webber, 1973). This type of problem is recognized because there is no definitive formulation of the problem, differing from the simple or tame problems in which the problem definition is clearly stated from the beginning. Although complex problems may have a feasible solution, it is not necessarily simple to implement. Among the methods for dealing with these problems (Kosow & Gaßner, 2008), General Morphological Analysis (GMA), a method developed by Fritz Zwicky in the 60s, is recognized to be a useful tool (Ritchey, 2011). This method attempts to investigate and to structure the whole set of relationships contained in a multidimensional and non-quantifiable complex problem.

In a CDIO academic program, it is essential to answer the following question: "What is the set of curricular and administrative strategies, systematically organized, to train the students in the skills projected in a curricular plan?". In this sense, the GMA methodology was applied to the curricular proposal of the Electronic Engineering Program at the Universidad del Quindío, Colombia, to identify these strategies under the assumption of different scenarios.

In this paper, based on the CDIO standards 7, 8, 9 and 10, eleven (11) parameters or dimensions for the proposed problem were defined. Then, considering each parameter individually, values that are potential solutions were proposed and selected. This set of values and parameters constitutes a problem space with a total of 4608000 initial solution alternatives. With the application of the GMA methodology, the solution space is reduced by 98.69%. Within the solution space, four (4) scenarios were reviewed: two scenarios contrast the current state and the desired state of the curricular implementation, and the other two scenarios contrast the institutional elements with those of the academic program. As a result, alternative solutions were obtained and evaluated qualitatively from the solutions provided by the analytical tool.

BACKGROUND AND CONTEXT

In this section, a brief description of the GMA methodology is presented, followed by the analysis of the current institutional and administrative context. This analysis provides a framework for the definition of the parameters and values that are used in the GMA methodology.

GMA methodology

One of the main features of a complex problem is that it has several stakeholders with different expectations (Rittel & Webber, 1973). Hence, the identification of the most suitable way to implement a CDIO program is as a complex or wicked problem, since students, faculty, administrators, alumni, industry partners, among others, are seeking out for different goals in the educational process. In this paper, we use the General Morphological Analysis (GMA) to deal with this complex problem. In GMA, we start identifying the set of parameters (or dimensions) that structure a problem, and for each parameter, we define the set of values that are alternative solutions within the context of the given parameter (Ritchey, 2011). Subsequently, alternative solutions that are compatible with the values across different parameters are analyzed by means of the cross-consistency assessment technique, providing a consistent and coherent solution space for the complex problem.

The CDIO Implementation at Universidad del Quindío

To understand the implications of implementing a program in the CDIO initiative, it is important to analyze a particular context, in this case, the Electronic Engineering Program at the Universidad del Quindío, Colombia. In the GMA methodology, these implications establish the problem parameters and their possible solutions. Other programs and institutions may have similar situations. Hence, the following discussion is emphasized not only in the particular issues at our university but also in the ideal case and situations in other institutions.

The University of Quindío joined to the CDIO initiative in 2014, with Electronic Engineering being the pilot program for the implementation. The institution has general guidelines for the curricular design of academic programs, a regulation for faculty hiring and training, faculty evaluation and student evaluation.

With respect to the curricular design, the University has a Curricular Academic Policy that defines the distribution of academic activities, establishes the mandatory courses for all students, and provides flexibility for the programs to define the curricular structure of the professional component. On the total credits for a given program, approximately 80% is defined by each academic program. Likewise, for all engineering programs, a common core has been defined, which establishes certain common courses in mathematics, physics and administration for all engineering students at the university. This policy also defines that the educational framework should be based on competences, which are compatible with the intended learning outcomes (ILOs), as established in the CDIO initiative (Biggs & Tang, 2011; E. Crawley et al., 2007). In some institutions, the curricular design may be less flexible, and the courses are commonly structured in learning objectives rather than ILOs, which are inappropriate for a CDIO-based approach.

Regarding the regulation of the faculty hiring, there are two types of contracts, full-time professors and partial-time professors. The first ones have a dedication 100% of the time to the University. In addition to their teaching activities, these professors have recognition in their weekly schedule to provide students' advisory, and to develop research and outreach activities. On the other hand, partial-time professors are hired on the hour-basis to attend exclusively classroom activities with no recognition for students' advisory, research or outreach activities, as they are usually people working in other institutions or companies. In the Electronic Engineering Program, there are a slightly higher number of full-time professors (62%) than partial-time professors (38%). This hiring model is widespread in all public institutions in Colombia, where most of them are partial-time professors. This model may differ from the context of the majority of higher education institutions in other countries, where a larger number of faculty staff is dedicated exclusively to the academy. On the other hand, not all faculty members are joined exclusively to the program, since some courses such as mathematics and physics are taught by professors from other academic units. These professors are usually no committed with the articulation of the CDIO. This last situation is common in other institutions, where departments on mathematics and physics offer generic courses for a diverse group of students.

Full-time teachers are the only ones who have the right to access the majority of the benefits of the faculty training plan. Similarly, financial resources for training are very limited, so it is not always possible to provide full funding for all teachers in a particular activity. To deal with this situation, our program constituted a weekly two-hour faculty meeting since 2010, where continuous training workshops are held to implement the CDIO initiative, and relevant issues for the curricular enhancement are also discussed.

In the institutional regulation for faculty evaluation, standardized instruments are applied for all professors without considering specific conditions. For example, a professor who does not research is also evaluated for this condition. Only surveys aimed at students and the director of the program are employed to collect the evaluation evidence. However, no effective feedback mechanisms are provided for the teacher beyond a quantitative value for purposes of ranking and hiring. The usefulness of this faculty evaluation approach has been strongly criticized, and it has been recently under review. In contrast, one of the ideal conditions w.r.t. faculty evaluation for an efficient CDIO implementation is to have varied instruments and based on diagnostics, to provide teacher advisory in his/her pedagogical practices. This ideal model suggests the existence of institutional supporting units.

For the organization of the academic activities, all the academic programs at the University follow the national guidelines, which are structured in academic credits. An academic credit is a measure of the student's time, including class hours, advisory and independent work. Although faculty have academic freedom to organize their work at the classroom level, institutional regulations require that instructional activities are carried out under a competency-based approach, and planned according to academic credits, so that they do not exceed the number of weekly hours defined in the curricular design. Although this approach is common to many nationwide and international institutions, there are regulation gaps regarding the guidelines for development and assessment of personal, interpersonal, and professional skills, as it will be addressed below.

Regarding the evaluation of the students, the current institutional regulation defines that each professor must define a minimum of three (3) assessments along the semester, in a cumulative fashion, and the result of each assessment must be known as a minimum one week after applied. Although this situation is similar in many institutions, this approach is incompatible with CDIO, since monitoring the development of personal, interpersonal and professional skills implies a formative instead of cumulative evaluation along the semester. To carry out a student evaluation compatible with CDIO and the institutional regulations, some professors have used a hybrid model that includes formative evaluation and cumulative evaluation in projects deliverables or particular topics.

METHODOLOGY

As explained in Section 2.1, under the GMA methodology, we start by defining the parameters (or dimensions) and the values (alternative solutions) for each parameter. Since we are particularly interested in the CDIO implementation given a previous curriculum design, this paper is mainly addressed by the classroom strategies, administrative issues, faculty skills, and the faculty relation with the external environment. Hence, the parameters of this complex problem are based on the CDIO standards 7 (Integrated Learning Experiences), 8 (Active Learning), 9 (Enhancement of Faculty Competence), and 10 (Enhancement of Faculty Teaching Competence). Eleven (11) parameters were selected, and their values are shown in Table 1. For each parameter, potential solutions or values were identified. These parameters and values are detailed as follow:

Table 1. Parameters and values of the problem space

A	B	C	D	E	F	G	H	I	J	K
v1	*v1*	*v1*	*v1*	*v1*	*v1*	*v1*	*v1*	*v1*	*v1*	*v1*
v2	*v2*	*v2*	*v2*	*v2*	*v2*	*v2*	*v2*	*v2*	*v2*	*v2*
v3	*v3*	*v3*	*v3*	*v3*	*v3*	*v3*	*v3*	*v3*	*v3*	*v3*
v4	*v4*	*v4*	*v4*	*v4*	*v4*	*v4*		*v4*	*v4*	
v5		*v5*			*v5*					

A. Mechanisms to implement learning experiences for the simultaneous development of personal, interpersonal, disciplinary and CDIO skills.
   - v1. Compulsory assessment at each cohort (semester, year, core) for personal, interpersonal, disciplinary and CDIO skills.
   - v2. Freedom of each teacher in their academic space to decide how to implement strategies for skills' development.
   - v3. Compulsory evaluation at each course for personal, interpersonal, disciplinary and CDIO skills.
   - v4. Specialized academic spaces for training of disciplinary, personal, interpersonal and CDIO skills.
   - v5. Co-curricular challenges in which students of different levels and programs interact each other or with external professionals (e.g. contests, hackathons, mentoring, etc.).

B. Management of the relationship with the external environment (industry partners, graduates and stakeholders) for the definition of learning experiences.
   - v1. Support on institutional bodies for the search of external problems and their solution with students
   - v2. Administrative unit at the program responsible for the identification of interested parties and external problems that may be addressed by students.
   - v3. Teachers and researchers in contact with the industry, responsible for problem identification and development of projects with students
   - v4. Classroom challenges where students in association with companies identify problems and seek out their solution in a given academic space.

C. Evidence for the implementation of integrated learning experiences.
   - v1. Only Syllabus. Course syllabus incorporates projected activities as integrated learning experiences, and it is the only evidence of application.
   - v2. Term report. Teacher's report with statistics on the learning experiences conducted in the courses and student projects.
   - v3. Survey. Survey applied to the actors of the learning process (students and teachers) on learning experiences integrated to classroom activities, tutoring, etc.
   - v4. Compilation of logbooks. Implementation of logbooks for all student activities, signed by the involved actors (students, tutors, stakeholders, etc.).
   - v5. Compilation of rubrics. Design and application of rubrics with visible criteria for integration of skills in a given academic space.

D. Guidelines for the application of active learning strategies according to topic cores, functional ILOs, and declarative ILOs.
   - v1. Definition of active learning strategies in the syllabus.
   - v2. Freedom of each teacher in their academic space.

v3. Definition of active learning strategies by topic core.
v4. List of suggested active learning strategies for each academic space.

E. Evidence for the implementation of active learning strategies.
  - v1. Only Syllabus. Course syllabus incorporates projected activities as active learning experiences, and it is the only evidence of application.
  - v2. Term report. Teacher's report with statistics on the active learning experiences conducted in the courses and student projects
  - v3. Survey. Survey applied to the actors of the learning process (students and teachers) on active learning strategies used in the classroom.
  - v4. Compilation of logbooks. Implementation of logbooks for all student activities, signed by the involved actors (students, tutors, stakeholders, etc.).

F. Criteria for the definition of the faculty profile (professional and pedagogical skills)
  - v1. Basic profile in pedagogical and professional skills to hire new faculty members, and desired profile to engage faculty in an enhancement plan.
  - v2. Definition of two (2) profiles for different faculty members: a) Teacher/researcher; b) Teacher/External collaborator; with minimal pedagogical skills.
  - v3. Generic profile defined by the Program Council for all faculty members.
  - v4. Unified profiles based on the skills established for each topic core.
  - v5. Individual profiles based on the skills stipulated in the course syllabus.

G. Guidelines for the training the faculty members in professional skills
  - v1. Compulsory linking of the faculty with industry partners (to participate in internships or to develop projects).
  - v2. Generic training for all faculty members.
  - v3. Personalized training according to the individual conditions of the faculty members.
  - v4. Definition of faculty training by areas.

H. Management of the faculty relationship with external stakeholders.
  - v1. Support on institutional bodies for faculty internships or project collaboration with industry partners.
  - v2. Administrative unit at the program responsible for the management of faculty internships or project collaboration with industry partners.
  - v3. Individual efforts. The faculty himself must seek and manage his opportunities for internship or project collaboration with industry partners.

I. Diagnosis of faculty competences in pedagogical skills
  - v1. Document resulting from the faculty meetings, where teachers share experiences.
  - v2. Test on pedagogical skills.
  - v3. Use of institutional instruments for the diagnosis of pedagogical skills.
  - v4. Survey aimed teachers on pedagogical competences.

J. Guidelines for the training the faculty members in pedagogical skills
  - v1. Compulsory participation in a minimum number of pedagogical events per year.
  - v2. Trainings by groups of teachers according to diagnosis.
  - v3. Individual training based on self-diagnosis.

v4. Generic training for all teachers.

K. Management of the faculty relationship with academic networks
   v1. Support in agreements with academic networks for academic mobility and cooperation.
   v2. Administrative unit at the program responsible for the publication and targeting of alternatives for participation in academic networks.
   v3. Individual efforts. The teacher seeks and participates in academic networks, also propose the creation of new networks.

According to the GMA methodology, the convenience (or compatibility) of each value in a given parameter was analyzed with all the remaining parameter values, obtaining a consistence matrix that is used for the analysis presented in the next section. This matrix was introduced in a software tool, developed by the authors, to visualize the values that could exist under the criterion of compatibility and convenience. Likewise, this tool allows selecting exclusively a value from each parameter of interest and contrasting it with the compatible values of the remaining parameters, according to the GMA methodology.

RESULTS

The problem space analyzed in this paper is composed of eleven (11) parameters, whose values were described in the previous section. The original problem space provides a total of 4608000 solution alternatives before applying the GMA. With the application of the analysis, the solution space is reduced by 98.69% (60455 solution alternatives).

In order to reduce the complexity of the problem, two subspaces were also proposed. The first sub-space considers five (5) parameters (A through E) related to the training strategies (standards 7-8) and the second subspace considers six (6) parameters (F through K) associated with the qualification of the human resource (standards 9-10). In the first subspace, 322 morphotypes were found, while in the second subspace, 476, for a total of 153272 solution alternatives. This would represent an increase of the solution space of 153.53%. As a result, it is convenient to analyze the problem with a single space of 11 parameters.

Starting from the solution space with eleven (11) parameters, we decided to analyze four (4) scenarios, which are the most relevant according to the policies and guidelines for academic programs in Colombia. These four (4) scenarios correspond to the current state and desired aspects of the curricular implementation, as well as institutional elements and those of the academic program. Alternative solutions were obtained based on these scenarios, and they were evaluated qualitatively by the analysis tool. The proposed scenarios respond to different institutional contexts, which would allow the application of these results to other academic programs. For each scenario, different solutions were analyzed by selecting some parameters and values, according to the situation that defines it, and the tool indicates the path of compatible values. To perform the analysis, a hierarchical analysis was established in the parameter order A, D, K, H, B, F, I, C, E, G, and J. In the following scenario descriptions, the selected parameters and values are written in the following way: *Parameter-Value*, e.g. A-v2.

Scenario 1: Current State. This scenario obeys to the current situations of the academic program and the institution, described in Section 2.2. This scenario is based on the professor's freedom for planning activities, integration of the CDIO initiative in his courses, and his absolute responsibility in the insertion on academic networks. In this scenario, the definition of faculty profiles is also established as the responsibility of the Program Council of the program.

- *Selected values:* A-v2; D-v2; K-v3; H-v3; B-v1 (restricted by the tool); F-v3;
- *Result:* It was identified that supporting units or institutional offices are necessary for the faculty enhancement on professional skills and the development of activities with external stakeholders. Likewise, the documents (term reports or surveys), carried out in the faculty meetings at the end of each academic term, are the preferred tools for diagnosing teachers' competences and monitoring the implementation processes. In this scenario, it is also concluded that teachers are responsible for seeking mechanisms to develop their professional skills.

Scenario 2: Desired. It arises from ideal conditions, which would be expected to have the institution and the academic program. This scenario proposes the presence of specialized academic spaces for training the skills projected in the graduate profiles. With respect to the remaining academic spaces, the active learning strategies must be clearly specified in their respective syllabus. It also considers the existence of a committee or administrative unit in the academic program for the interaction with external stakeholders and academic networks. Besides, this scenario takes into account the definition of a basic faculty profile in pedagogical and professional skills for new hiring or engagement in a faculty training plan.

- *Selected values:* A-v4; D. v1; K. v2; H. v2; B. v2; F. v1; I. v1
- *Result:* In this scenario, the mechanisms for collecting evidence are flexible, excluding the strategy based exclusively on the syllabus. In terms of faculty training, there is also flexibility, but the alternative of a specialized training by areas is not feasible.

Scenario 3: Institutional line. In this scenario, values are selected based on the mechanisms and guidelines currently supported by the institution. This scenario is characterized by the dependence on departments or institutional offices for the realization of agreements, training, access to academic networks, etc. At the classroom level, there is a clear definition of active learning strategies in the syllabus for each academic space, as well as the mandatory application of assessment tools in each course for the monitoring of skills.

- *Selected values:* A-v3; D-v1; K-v1; H-v1; B-v1; F-v3; I-v3
- *Result:* In this scenario, the mechanism for collecting evidences of the implementation of integrated learning and active learning experiences are reduced to the compilation of logbooks. For the specific case of integrated learning experiences, the option of compilation of rubrics is also valid. Among the guidelines for faculty training, the availability of generic training and personalized training stands out.
  If the selection of the value for the parameter A (integrated learning experiences) is changed to v4 (co-curricular challenges), the valid mechanism for collecting evidence is only the compilation of rubrics.

Scenario 4: Program Line. The values selected for this scenario are based on the mechanisms and guidelines currently supported in the program. This scenario is characterized by the existence of an administrative unit in the academic program for the relationship with the external stakeholders. At the classroom level, there is a clear definition of active learning strategies in the syllabus for each academic space, as well as the mandatory application of assessment tools at each course for the monitoring of skills.

- *Selected values:* A-v3; D-v1; K-v2; H-v2; B-v2; F-v3; I-v1

- *Result:* The mechanisms for collecting evidence to monitor the implementation of integrated learning and active learning experiences are flexible, allowing the use of term reports, surveys or compilation of logbooks or rubrics. The alternative based exclusively on the syllabus is not feasible. The faculty training can be generic or personalized. If the selection of the value for the parameter A (integrated learning experiences) is changed to v4 (co-curricular challenges), the allowed mechanisms for collecting evidence are the survey and the compilation of logbooks.

As a general observation for all scenarios, the selection of the freedom of each teacher in their academic space for the parameter D (guidelines for the application of active learning strategies) reduces significantly the solution space. However, this selection is inconvenient because it constrains the available values in the remaining parameters, and it is incompatible with the integrated curriculum, which is an essential element in the CDIO approach.

In the current context, the professor has the freedom to implement strategies for active learning (parameter D), and assessment of personal, interpersonal and professional skills (parameter A). Besides, in the current context, the relationship with external stakeholders and academic networks relies exclusively on individual efforts of the faculty (parameters B, H an K). In contrast, the GMA analysis suggests that an efficient implementation of the CDIO initiative involves the adoption of clear strategies and policies, at the program and institutional levels, as well as the existence of administrative units to lead these processes. The latter issues are suggested by the values obtained for scenarios 2, 3 and 4.

CONCLUSIONS

In this paper, the general morphological analysis (GMA) was applied to identify suitable solution alternatives for the implementation of a CDIO program according to standards 7, 8, 9 and 10. In our analysis, we assume that the curricular design (standards 1-4) was previously performed. Therefore, we are focused on learning strategies, and administrative and faculty issues. Based on the standards, we proposed eleven (11) parameters and their corresponding values. By using GMA, the solution space is significantly reduced. This solution space is analyzed under four (4) scenarios: the current state, the desired state, a state based exclusively on institutional guidelines, and a state based on both institutional and program guidelines. Solutions for these scenarios were clearly exposed and important remarks are discussed. The proposed scenarios can be fitted to different institutional contexts, according to the proposed parameters and values. Hence, this analysis can be applied to other academic programs to assess and project qualitatively and quantitatively their curricular profiles.

REFERENCES

Biggs, J. B., & Tang, C. S.-k. (2011). Teaching for Quality Learning at University: What the Student Does. Maidenhead: Society for Research into Higher Education & Open University Press.

Crawley, E., Malmqvist, J., Ostlund, S., & Brodeur, D. (2007). Rethinking engineering education. The CDIO Approach (2nd ed.). Switzerland: Springer.

Kosow, H., & Gaßner, R. (2008). *Methods of future and scenario analysis: overview, assessment, and selection criteria*. Bonn: Dt. Inst. für Entwicklungspolitik.

Rittel, H. W. J., & Webber, M. (1973). Dilemmas in a General Theory of Planning. *Policy Sciences*, *4*, 155-169.

Ritchey, T. (2011). *Wicked Problems – Social Messes*. Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-19653-9

BIOGRAPHICAL INFORMATION

Jorge Iván Marín holds degrees in Electrical and Electronic Engineering, Master of Materials Science at the University of Quindío, Colombia, in 1997 and 2004, respectively, and a Ph.D. in Electrical and Computer Engineering at the Georgia Institute of Technology, Atlanta, United States, 2012. In 2001, he joined to the Electronic Engineering Program at University of Quindío, where he currently teaches in the areas of Digital Systems and Signal Processing. He is also the director of the research group in Digital Signal Processing and Processors (GDSPROC). Since 2012, he has been involved in the leading team to implement the CDIO initiative in the Electronic Engineering Program.

Alexander Vera-Tasama holds degrees in Electronic Engineering (2003), Ph.D. in Electronic Engineering (2015) at the University of Valle, Colombia, and a Specialist degree in Radio communications at the University of Quindío, Colombia, 2008. Since 2001, he has been professor, but in 2006 he joined to the Electronic Engineering Program at University of Quindío, where he joined also to the GDSPROC research group as member. He currently teaches in areas of Digital-systems design and Electronic-product design, which are his main fields of interest, and researches on digital systems and didactic resources for engineering education. Now, he has been involved in the faculty team to implement the CDIO initiative in the academic program.

Jaiber Evelio Cardona holds degrees in Electronic Engineering (1998), Master on Automation (2004) and Ph.D. in Electronic Engineering (2018) at the University of Valle, Colombia. In 2005, he joined to the Electronic Engineering Program at University of Quindío, where he currently teaches in the areas of Control Systems and Automation. He is also the director of the research group in Automation and Machine Learning (GAMA).

Corresponding author

Jorge Iván Marín, Ph.D
Universidad del Quindío
Local Address: Cra. 15 Cll. 12N
Armenia-Quindío
Colombia
jorgemarin@uniquindio.edu.co