CDIO AND COMPETENCY-BASED LEARNING APPROACHES APPLIED TOGETHER TO MILITARY ENGINEERING EDUCATION

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ABSTRACT

The CDIO consists of a curricular approach customized to the reality of engineering undergraduate courses, considering several specialties, and which was built from a large-scale survey of knowledge, skills and psychological characteristics currently required of the engineer. On the other hand, competency-based learning is a methodology that is used in several courses in the Brazilian Army, which connects different areas of knowledge and, instead of focusing on theory, aims to prepare for a professional action that mobilizes knowledge, resources, attitudes, values, and skills in specific situations in professional life. In this methodology, students have access to a curriculum made up of integrated modules to develop new capacities, practical, technical, cognitive, and socio-emotional skills and to teaching based on problem situations. In this context, it is possible to identify the synergy between these two approaches. It was precisely the convergence between these two curriculum construction systems that made it possible to develop a hybrid methodology at the Military Institute of Engineering (IME), which integrated the CDIO and the Competency-based Learning methodologies used by the Brazilian Army. It should be noted that another challenge is to keep this hybrid methodology in line with the Curriculum Guidelines for engineering education in Brazil. Therefore, this paper makes a comparison between the main concepts and the sequence of actions necessary to build an innovative curriculum, contemplating both approaches, which can facilitate the understanding of the reform currently underway at this Institute.

KEYWORDS

Constructive alignment, academic implementation, innovation. Standards: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

INTRODUCTION

Competency-based learning has marked the recent evolution of professional education due to the predominance of situations involving complexity and uncertainty in the engineering work environment, which requires an undergraduate course that provides an interdisciplinary character and the development of teamwork skills. Thus, it is not enough for engineering professionals to have a solid scientific base, although it continues to be essential. It is also necessary for the engineer to integrate theory into professional practice through effective knowledge transfer strategies, in concrete situations in the world of work.

In this direction, from the 1990s onwards, the CDIO Initiative proposes a teaching methodology based on competences that involves a systematic curriculum construction and suggests a set of didactic procedures, based on the mapping of the so-called macro competences of the engineer – conceiving, designing, implement and operate – to which a repertoire of skills, knowledge and attitudes is linked. This mapping was carried out in the job market, on a large scale, considering the professional reality of several countries.

In Brazil, competence learning in the engineering area was initially regulated through the National Curriculum Guidelines (NCGs) for undergraduate engineering courses in 2002 (Brazil, 2002), which aimed to train professionals in accordance with the current needs of society and the labour market, by determining an engineer's profile based on a humanistic, interdisciplinary, and reflective approach. This approach was intensified in 2019, when the Brazilian Ministry of Education established the new NCGs for the undergraduate courses in engineering (Brazil, 2019b), and which required the explicit formulation of systematic curriculum planning, didactic and evaluation procedures, both within the scope of the Course Pedagogical Project and in the curricular documents of the engineering courses.

In this context, in order to help engineering courses in Brazil and Latin America, it is considered important to describe the pedagogical tools that are currently being introduced at the Military Institute of Engineering to meet the requirements of the new NCGs in this area, explaining the logic of construction, invention and recreation, and the synthesis of existing methodologies, analysing how they are adapted to each field of engineering, the organizational culture of the engineering school and the characteristics of teachers and students.

In this perspective, this work analyses the creation of the curriculum construction methodology of the IME, which incorporated elements of the CDIO, of the new NCGs for the Brazilian graduation courses in engineering and of the competency-based learning of the Brazilian Army, from a collective process of customization carried out through a partnership between the Department of Science and Technology (DCT) of the Brazilian Army and the IME, based on the management of a group of implanters from the IME, formed by five leading professors called the G-5, a team composed of twenty professors who coordinate the ten undergraduate courses at the IME, called the G-20, and two pedagogical advisors, one from the DCT and one from the IME.

Therefore, the IME's curriculum construction methodology assimilated concepts and procedures from three approaches: the CDIO, the new guidelines for the Engineering course and the competency-based learning of the Brazilian Army. They are methodologies that provide important concepts about the act of teaching and learning, suggesting sequences of procedures for constructing or diagnosing curricula, as well as didactic activities and learning assessment.

APPROACHES TO CURRICULUM FRAMEWORK DEVELOPMENT

CDIO Approach

The CDIO approach was developed by the Department of Aeronautics and Astronautics Massachusetts Institute of Technology (CDIO, 2022), in response to two demands: on the one hand, an exponential increase in technical knowledge in engineering and related areas; on the other hand, the perception that engineers should have diverse attributes and skills of

a personal and interpersonal nature, which would allow their participation in work teams to produce products and systems.

To develop the CDIO Syllabus (Crawley, Malmqvist, Brodeur, Östlund, & Edström, 2014), which outlines the attributes and desirable characteristics of the engineer, the CDIO Initiative carried out a broad mapping of the knowledge, skills, and abilities of engineers, in various fields of engineering and in many countries.

Thus, the CDIO Syllabus establishes the main professional requirements for the exercise of the activity that must be considered by engineering courses, considering the norms and guidelines of professional engineering practice and other aspects considered relevant by other professionals in the field. It is subject to customization in the most diverse contexts of professional action and can be made more flexible based on different organizational cultures, making explicit the levels of excellence in carrying out tasks. It is also possible to use the Syllabus in personnel selection and personnel training processes in companies and professional training in higher education courses in engineering. The Syllabus contains wide-ranging professional activities: conceive, design, implement and operate products and systems.

The Syllabus is also used as a starting point to develop learning outcomes and build the school curriculum, highlighting the role of engineering sciences and scientific research in the area. Includes the following components: technical knowledge and cognitive skills; personal and professional skills; and interpersonal skills.

Among the individual's skills, there are skills of a professional nature, such as problem solving, scientific discovery and systemic thinking, as well as oral and written communication, use of information and communication technologies, in addition to those related to professional ethical behaviour. The Syllabus also includes some characteristics of the person, such as initiative and perseverance, creative and critical thinking, intellectual curiosity, self-improvement, and teamwork attitudes.

For curriculum implementation, the CDIO Initiative suggests the CDIO Standard as best practice (Ulloa, Villegas, Céspedes, & Ramírez, 2014). The CDIO Standard involves preparing the course to achieve the learning outcomes by adapting appropriate teaching-learning practices, using labs, and assessing learning.

New Brazilian Curriculum Guidelines for engineering education (NCGs)

Coordinated by the National Council of Education and composed of specialists from the academic, professional and business sectors with knowledge in the axes of the guidelines, the new NCGs were built from five thematic subcommittees, guided by the general coordination, in order to produce a support document (BRAZIL , 2019a). One of the objectives is to reduce school dropout, which is common in undergraduate engineering courses in Brazil, proposing a new teaching-learning model for teaching engineering, different from the old model of lectures and solving book exercises, considered, in part, as responsible for the low intellectual performance of students.

The new NCGs is a law document for engineering education based on the well-known KSA - knowledge, skills, and attitudes - that constitute the competencies for the future engineer. There is also evidence of explicit adherence to an approach centered on active learning,

which consider the student as the protagonist of the teaching-learning process (CNI et al., 2020).

The main objective of this document is to promote a closer articulation of engineering courses with the market, with the productive segments and with professional councils, which requires the elaboration of flexible study programs, in permanent evolution, permeated by integration activities. In short, a curriculum that manages to reproduce the real working conditions of the engineer, which is not the case of traditional curricula, of a theoretical nature, and of compartmentalized knowledge.

In fact, the new NCGs invert the relationship between content and profile, in the sense of starting with the final product of the process (the graduate's profile) and structuring training from there backwards, breaking with the logic of starting curriculum design with offer of content available in the institutions to reach the egress profile from there (CNI et al., 2020).

In this way, teaching strategies such as project pedagogy and the elaboration of learning outcomes replace the exclusive focus on the transmission of bookish knowledge. In a sense, the new NCGs are impregnated with pedagogical logics that emphasize the act of learning, and the development of students' abilities and skills. From this perspective, as part of the pedagogical process of the NCGs, there are detailed requirements to be made in the Course Pedagogical Project, which must include the competences to be developed, both general and specific, articulated to the activities of teaching-learning and those of a complementary nature. In the field of didactics and assessment, theory and practice and the context of application are associated, necessary for the development of skills, through active methods, centred on teamwork, focused on simulating real work situations, both in the classroom and in extension actions and in the various forms of industry-school integration.

Several activities that promote integration and interdisciplinarity are also proposed. To this end, NCG suggests carrying out scientific initiation work, academic competitions, interdisciplinary and transdisciplinary projects, extension projects, volunteer activities, technical visits, teamwork, prototype development, monitoring, participation in junior companies, incubators, and other entrepreneurial activities (BRAZIL, 2019b). According to the methodology, the curriculum can be built through the following steps (CNI et al., 2020):

- Determine a set of competences of the graduate (general and specific).
- Indicate specific skills.
- Structure the learning outcomes related to specific skills.
- Select the teaching contents so that the learning outcomes are achieved.

The NCGs prescribe a list of practical activities and learning spaces, which can be: presential, virtual, remote, itinerant (on mobile equipment) or collaborative (in partnerships with public and private institutions). Regarding assessment, the new NCGs emphasize some pedagogical principles and continuous assessment, which do not prioritize only the mention of a degree (formative assessment); the diversification of assessment instruments, which can be done through monographs, exercises or dissertation tests, presentation of seminars and oral practices, reports, projects and practical activities, among others, that demonstrate learning and stimulate the intellectual production of students, individually or in a team (CNI et al., 2020).

Finally, the NCGs describe content as factual, conceptual, procedural knowledge related to the cognitive capacities of remembering, understanding, and applying, in addition to more

complex cognitive processes such as evaluating, analysing, and creating. Other recommended methodological indications are the following curriculum construction strategies (CNI et al., 2020):

- Correlate the general objectives of the course with the egress profile.
- Build a framework relating the overall objectives of the course with specific objectives of the tracks and curricular components.
- Divide each objective (competence) into its components (skills, knowledge, and attitudes).
- Build a framework relating different assessment instruments and the components with which they can assess, as well as the respective cognitive dimension.
- Relate each competence with the evaluation instruments used.

The Brazilian Army curriculum construction methodology

The Brazilian Army was based on the methodology of SENAI - National Industrial Learning Service (SENAI, 2009), inserting important customizations such as the Transverse Axis, containing skills, attitudes, and values inherent to the engineering profession. This Transverse Axis was obtained through a brainstorm carried out by professionals with different levels of professional experience related to their respective qualification area.

Some customizations are due to what already existed before the implementation of teaching by competencies in the Brazilian Army. For example, the psychological characteristics of graduates were described in the Professional Profile, a document that remained after the change in the educational paradigm, incorporating the mapping of competences, which is a document called the Functional Map, in addition to presenting a selection of components of the Transversal Axis.

That is, the Professional Profile still establishes the personality traits of the graduate, as was done before, but its indication is now based on an inference process centred on the description of the work activity, which appears in the Functional Map. From there come the elements of the so-called Transversal Axis, which permeate the entire curriculum, in the curricular, didactic and evaluation aspects. Next, the methodology of the Brazilian Army stipulates that the Integrated Plan of Disciplines (IPD) be completed, which explains what the contents are necessary to carry out an interdisciplinary activity. The Discipline Plan (DP) is also completed simultaneously with the IPD, as it is necessary to establish the disciplines at the same time as the intersections between them. The elements of the Transversal Axis are also included in the IPD and DP (BRASIL, 2022).

In this methodology, there are three types of disciplines:

- Disciplines directed to competences.
- Disciplines for the development of existing skills, attitudes and values in the Transversal Axis.
- Disciplines of fundamentation and instrumentalization, which establish the bases of disciplinary knowledge and provide the learning of useful technical knowledge in various disciplines and different work activities.

Finally, the Course Pedagogical Project is the document that consolidates the existing information in the Professional Profile, in the Integrated Plan of Disciplines and in the Discipline Plans. The General Table of School Activities is presented in the Course

Pedagogical Project, which is a document that contains the distribution of the workload of subjects and integration activities. In addition, the Course Pedagogical Project shows constructive alignment (Biggs, 1996) as a way of evolving the undergraduate course, the characteristics of faculty training and the methodology for evaluating the program and possible improvements.

Regarding the pedagogical methodology of the Brazilian Army, priority is given to active teaching-learning methods, centred on the student, such as various types of academic group activities, project-based learning, and problem-solving methods. Several systematic planning and evaluation of the so-called learning contents are also proposed: factual, conceptual, procedural, and attitudinal, which are distinguished according to different teaching-learning processes, requiring different didactic and evaluation procedures (Coll, Pozo, Sarabia, & Valls, 2020). In turn, in the educational evaluation part, several instruments are foreseen. In addition, there are tools for checking results in assessments that are capable of scaling student performances, based on certain criteria (BRAZIL, 2020).

THE CHALLENGE OF METHODOLOGICAL INTEGRATION

The new NCGs indicate all the requirements that must be present in the Course Pedagogical Project to meet the needs of the engineer who graduated from a Brazilian university. In summary, the Course Pedagogical Project must clearly contain the learning outcomes, all academic activities to achieve these objectives, teacher training and appropriate assessment forms for each type of activity selected. Academic activities involve lectures, active learning, extracurricular activities, teamwork, and use of laboratories. This concept of constructive alignment, present in all approaches presented in this work, is shown in Figure 1.

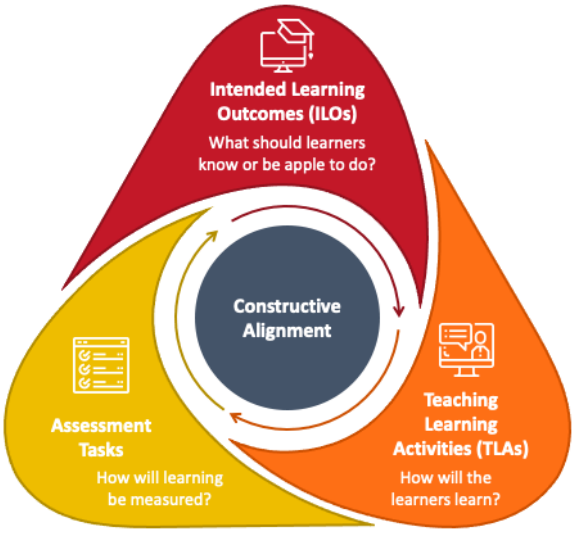

Figure 1: Constructive alignment (Biggs, 1996).

However, the NCGs do not show a methodology for curriculum construction. It should be noted that the Brazilian Ministry of Education conducts periodic evaluations of each undergraduate course to verify whether the respective Course Pedagogical Project complies with the NGCs. In case the Course Pedagogical Project does not comply with the NCGs, the undergraduate course may be disqualified to graduate new professionals.

The CDIO approach uses a curriculum construction methodology through the CDIO Standards. The content of the Course Pedagogical Project, determined by the NCGs, is very much in line with the topics to be developed by the CDIO Standards (Rezende, Neto, & Rodrigues, 2022).

The Brazilian Army curriculum construction methodology provides the documentation of the steps up to the final construction of the Course Pedagogical Project. In Brazil this is important because the Course Pedagogical Project is an evaluation document in according with the Brazilian education law. During the development of the Course Pedagogical Project, the documentation proposed by the Brazilian Army methodology was considered very useful, as it helped to consolidate the guidelines contained in the CDIO Standards, the needs prescribed by the new NCGs and the ideas of all participants in the curriculum construction process.

Table 1 shows the summary of the synergy between the existing curriculum construction topics in the new NCGs, in the CDIO Standards and in the methodology of the Brazilian Army.

Table 1. Alignment of the new NCGs propositions, CDIO Standards and documents in Brazilian Army methodology for the Course Pedagogical Projects.

Propositions for Course Pedagogical Project by NCGs	**CDIO Standards**	**Brazilian Army methodology**
Induction of innovative institutional policies	CDIO as context	Course Pedagogical Project
	Program evaluation	Course Pedagogical Project
Focus on teaching through skills development	Integrated curriculum	Integrated Plan of Disciplines
	Learning outcomes	Professional Profile Competences + Transverse Axis
Emphasis on managing the learning process	Introduction to engineering	Integrated Plan of Disciplines
	Integrated learning experiences	Integrated Plan of Disciplines
	Learning assessment	Discipline Plan
	Engineering workspaces	Discipline Plan
Relationship strengthening with different organizations	Design-implement experiences	Integrated Plan of Disciplines
Innovative teaching methodologies	Active learning	Discipline Plan
Valuing faculty training	Enhancement of faculty competence	Course Pedagogical Project
	Enhancement of faculty teaching competence	Course Pedagogical Project

Another topic for integrating the methodologies is the selection of knowledge, skills, and attitudes that engineering students should have when they leave university.

The participants began the curriculum design process through a careful study of the CDIO Syllabus, to compare it with the learning outcomes established by the Brazilian education laws, the engineering companies and society. For engineering higher education, the Brazilian law determines the learning outcomes are in accordance with the NCGs for engineering courses (Brazil, 2019b). To exercise the engineer profession, the Federal Council of Engineering and Agronomy (FCEA, 2005) establishes the activities, abilities, and responsibilities of the engineer. The knowledge, skills, and attitudes, determined by the National Curricular Guidelines of Engineering Undergraduate Programs (Brazil, 2019b) and by the Federal Council of Engineering and Agronomy (FCEA, 2005), present a strong similarity. In this way, Table 2 correlates the demands of National Guidelines and Federal Council of Engineering and Agronomy (FCEA, 2005) with the skills and knowledge proposed by the sections of the CDIO Syllabus.

Table 2. Correlation of competences between the Brazilian aspects and the CDIO Syllabus.

Competencies established by the NCGs and by FCEA		***CDIO Syllabus***
Apply mathematical, scientific, technological, and instrumental knowledge to the engineering	➡	*Disciplinary knowledge and reasoning*
Design and conduct experiments and interpret results	➡	*Personal and professional skills and attributes*
Planning, supervise, elaborate, and coordinate engineering projects and services		
Identify, formulate, and solve engineering problems		
Develop and/or use new tools and techniques		
Understand and apply professional ethics and responsibility		
Assume the posture of permanent search for professional updating		
Communicating effectively in written, oral and graphic forms	➡	*Interpersonal skills: teamwork and communication*
Work in multidisciplinary teams		
Conceive, design, and analyze systems, products, and processes	➡	*Conceiving, designing, implementing, and operating systems in the enterprise, societal and environmental context – the innovation process*
Supervise the operation and maintenance of systems		
Evaluate the impact of engineering activities in the social and environmental context		
Evaluate the economic feasibility of engineering projects		

Table 2 shows that the CDIO Syllabus addresses all the needs of Brazilian education laws and the exercise of engineering activity in companies (Federal Council of Engineering and Agronomy requirements). The Brazilian Army methodology involves military engineer skills with characteristics very similar to the CDIO Syllabus and will not be detailed in this paper.

Bearing in mind that the CDIO Syllabus is current research, which meets the needs of the modern engineer, the IME working group decided to adopt the CDIO Syllabus as a basis for choosing skills and attitudes, with the necessary customizations for each engineering program. Thus, as previously described, this knowledge, skills and attitudes will be present in the Professional Profile document.

FINAL REMARKS

The IME's curriculum construction methodology was built from the Brazilian Army methodology, the new NCGs and the CDIO approach, through customization procedures. The Brazilian Army's methodology was predominant due to its greater simplicity and because it was a curriculum construction methodology and not a diagnostic one, which was more important, allowing the quick execution of the teaching reform in ten engineering courses - a not insignificant factor in view of the pressing deadlines for the implementation of the new guidelines for engineering education, required by the Brazilian Ministry of Education, as well as for competence-based learning, demanded by the Brazilian Army.

Another relevant innovation in the face of the Army's methodology was the insertion of skills, which were included in the CDIO and in the new NCGs, and were incorporated in the Transversal Axis, to appear in Integrated Plan of Disciplines and Discipline Plan, with clear indications for their development in didactic situations and of evaluation.

It is important to highlight that, despite the IME methodology being based on curriculum construction, it is based on the analysis of existing curricula, which are subjected to criticism in the context of engineering programs and to a process of transposition to new models of documents to the new education curriculum. Numerous pedagogical training sessions were carried out for program coordinators to prevent the reform from merely changing terminologies, maintaining the same customary logic of content selection, based above all on school traditions. It is important to emphasize the fact that for more than 5 years the ideas of the CDIO and the methodology of the Brazilian Army have been disseminated through lectures and small training sessions for professors, facilitating the acceptance of IME faculty. The acceptance of active learning and interdisciplinary approaches is considerable, being marked by some spontaneous experiences of professors in different programs.

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