CDIO APPLIED IN THE BRAZILIAN ENGINEERING EDUCATION LAW IMPLEMENTATION

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ABSTRACT

The relevance of the new Brazilian Curriculum Guidelines (new NCGs) for engineering undergraduate courses coincides with the expectations of the academic community, companies employing this qualified workforce and the need to update education in the country, aiming to meet future demands for more and better engineers. In this sense, given the transformations that are taking place in the world of production and work, the new NCGs can stimulate the modernization of engineering courses, through continuous updating, centering on the student as an agent of knowledge, greater integration school-enterprise, the appreciation of inter and transdisciplinarity, as well as the important role of the teacher as an agent for conducting the necessary changes, inside and outside the classroom. However, engineering undergraduate courses find it difficult to adapt to the new NCGs, as they have had teaching practices based on lectures for many years, where the teacher transfers knowledge and the most important intellectual skill of the good student is the memorization of academic content and its repetition in tests. The purpose of this article is to present the implementation of the new NCGs through the CDIO approach. This implementation represents a change in the teaching and learning process, maintaining the excellence of the academic content, reorganizing the pedagogical project of the course, integrating new academic practices, and adding skills and competences necessary for the modern engineer. The implementation is shown through a case study involving the Mechanical Engineering undergraduate course at the Military Institute of Engineering and the initial results demonstrate an increase in student's motivation, innovation and problem solving in new academic activities of practical and active learning. Furthermore, this study demonstrates that the CDIO approach is a methodology aligned with the proposals of the new NCGs for engineering courses and aims to motivate other Brazilian universities to use CDIO.

KEYWORDS

Constructive alignment, academic implementation, innovation. Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

INTRODUCTION

Scientific and technological knowledge is advancing rapidly and undergraduate courses in engineering must prepare professionals to solve the demands of modern society and industry.

In Brazil, for projects and services involving engineering to have competitiveness and innovation in the international scene, it is necessary to graduate engineers with solid technical-scientific qualification, endowed with the skills and competences necessary for the creation and improvement of innovative products and processes, at the frontier of knowledge.

However, according to the National Education Council Report (Brazil, 2019a), the national productive sector finds it difficult to recruit qualified professionals to work at the frontier of knowledge, which, in addition to technique, requires its professionals to master skills such as leadership, teamwork, planning, strategic management and autonomous learning, which are known as soft skills. In other words, professionals are increasingly required to have solid technical knowledge, combined with a more humanistic and entrepreneurial vision.

Thus, considering that the engineering activity is essential in the generation of knowledge, technologies and innovations, and the consequent need to improve the quality of engineering undergraduate courses offered in the country, the National Council of Education edited the new National Curriculum Guidelines (NCGs) for engineering courses (Brazil, 2019b).

According to the National Education Council Report (Brazil, 2019a), the new NCGs for engineering courses have flexibility and diversity, guiding towards the integration of theory with practice, and teaching with research. They also represent an opportunity to propose new curricular organizations in Engineering. The new Pedagogical Course Projects (PCPs) must align the accumulated experiences of the faculty with the development of competences in the graduates of the courses, considering regional and institutional specificities. The following are some important considerations for implementing the new NCGs in engineering courses: involvement of professors and managers in the process of preparing new PCPs, which should provide innovation and flexibility in the teaching-learning process; development and/or revision of curricula, having as a starting point the desired competences for the graduates; teacher training to provide new teaching practices that provide active learning, required by the new NCGs; adaptations and investment in infrastructure to intensify active learning, such as: new teaching and learning environments, improvements to the laboratories for integrated projects, adequate teaching material, etc; management of student assessment and competency-oriented learning process instead of the content vision; and permanent interaction between academia and industry, all undergraduate degree in engineering.

However, the academic questioning of the various engineering undergraduate courses is how to carry out the necessary adaptation to the new NCGs and improve engineering education in the respective institution and in the country. In this context, some Higher Education Institutions (HEIs) in Brazil are adopting the CDIO approach (Crawley, Malmqvist, Brodeur, Östlund, & Edström, 2014) to plan and carry out such changes in engineering education in their respective courses.

The Mechanical Engineering course at the Military Institute of Engineering (IME) uses this CDIO model to adapt to the new NCGs, motivate its academic staff and, finally, make the future mechanical engineer capable of carrying out professional activities within the new demands and challenges of the industry and modern society (Cerqueira, Rezende, Barroso Magno, & Gunnarsson, 2016).

CDIO APPLIED IN A MECHANICAL ENGINEERING COURSE: CASE STUDY AT IME

The mechanical engineering undergraduate course in the Military Institute of Engineering (IME) has the basic contents for mechanical engineering, such as Thermodynamics, Fluid Mechanics, Dynamics, Solid Mechanics and Machine Projects. The academic period for the student to become a mechanical engineer by the IME is five years, divided into ten semesters. The first four semesters are the basic contents. Only after the fourth semester mechanical engineering students will have contact with the specific content. The mechanical engineering program has 3,600 hours of activities in engineering education.

The mechanical engineering at IME, to improve and transform its PCP, must agree with the new National Curriculum Guidelines (NCGs) of the Ministry of Education (BRAZIL, 2019b). Thus, a study was carried out to assess whether the academic premises of the new NCGs (BRAZIL, 2019a) were compatible with those proposed by the CDIO Standards, with the objective of an initial validation of the approach. The result of this preliminary comparison was that the use of the CDIO approach was appropriate, relevant, and aligned with the new NCGs. Table 1 shows the comparison topics.

The result shown in Table 1 motivated the application of the CDIO approach in the pedagogical improvement of the IME mechanical engineering courses and in their respective adaptation to the new NCGs. Thus, to implement the approach (Ulloa, Villegas, Céspedes, & Ramírez, 2014) the adoption process proposed by the CDIO Initiative (CDIO, 2021) was used.

Table 1. Alignment of the new NCGs propositions with the CDIO Standards, for the PCPs.

Propositions for PCPs by NCGs	CDIO Standards
Induction of innovative institutional policies	CDIO as context
	Program evaluation
Focus on teaching through skills development	Integrated curriculum
	Learning outcomes
Emphasis on managing the learning process	Introduction to engineering
	Integrated learning experiences
	Learning assessment
	Engineering workspaces
Relationship strengthening with different organizations	Design-implement experiences
Innovative teaching methodologies	Active learning
Valuing faculty training	Enhancement of faculty competence
	Enhancement of faculty teaching competence

The following subsections present the actions taken to adapt the mechanical engineering course to the CDIO Standards and, consequently, to the new NCGs.

CDIO Standard 1 (the context) and the new NCGs

Through presentations and meetings with mechanical engineering program faculty, the problems that generated the lack of motivation for the engineering learning and the current needs of the industries and the society were shown. The following subjects were discussed: very theoretical courses; lack of practice in disciplines; demotivation for learning; need for integration between disciplines (interdisciplinarity); there is no provision of improvement courses in teaching of higher education in engineering; and the current needs of the engineering professional, considering the skills and abilities proposed for the mechanical engineering course at the Federal Council of Engineering and Agronomy (FCEA), NCGs and CDIO Syllabus (Crawley, Malmqvist, Brodeur, Östlund, & Edström, 2014). In this context, the CDIO approach (CDIO Standard 1) was introduced as a solution, providing to the future mechanical engineers the ability to perform their engineering skills with a more mature assessment of how a product meets the real needs of the industry and society.

CDIO Standards 2 and 3 (learning outcomes and integrated curriculum)

The selection of the knowledge, skills, and attitudes that engineering students must have when leaving university is the next step in the development of the new PCP (CDIO Standard 2). Table 2 shows the context of Brazilian competences correlations.

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		

The mechanical engineering program 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 (Table 2).

For mechanical engineering higher education, the Brazilian law determines the learning outcomes are in accordance with the NCGs (Articles 3rd, 4th, 5th) for engineering courses (Brazil, 2019b). To exercise the mechanical 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 FCEA with the skills and knowledge proposed by the sections of the CDIO Syllabus.

Table 2 shows that the CDIO Syllabus addresses all the needs of Brazilian education laws and the exercise of engineering activity in companies (FCEA requirements). Given that the CDIO Syllabus is a current document, covering the needs of the modern engineer, the mechanical engineering program decided to adopt the CDIO Syllabus completely and without any customization. In this way, the CDIO Syllabus has been translated into Portuguese and is being submitted to the faculty for further development of the integrated curriculum. To this end, it is intended to use the tools called matrix ITUE Matrices and Black Box exercise (Crawley, Malmqvist, Brodeur, Östlund, & Edström, 2014). The need to improve engineering education in Brazil through an integrated curriculum is present in Article 6th of the new NCGs.

Standard 4 (introduction to engineering)

The discipline of Introduction to Engineering Project (IEP) was designed to be carried out in two periods, that is, in the third and fourth periods of the second year. The IEP courses are common to all the IME programs because students only start in their specialty from the fifth semester in the third year. The introductory engineering discipline is one of the guidelines contained in the new NCGs (Article 6th , Paragraph 4th). IEP I & II were implemented in 2018. The core of both courses is the theory and practice of Project Management (PM); active learning through project-based learning (PBL); design-build activities; teamwork strategies; and specific content for oral and written presentation development (Passos, Arruda, Vasconcelos, & Ferrari, 2019). During these two semesters, the practices become increasingly complex, always considering the student's level and knowledge. Figure 1 shows IEP I & II.

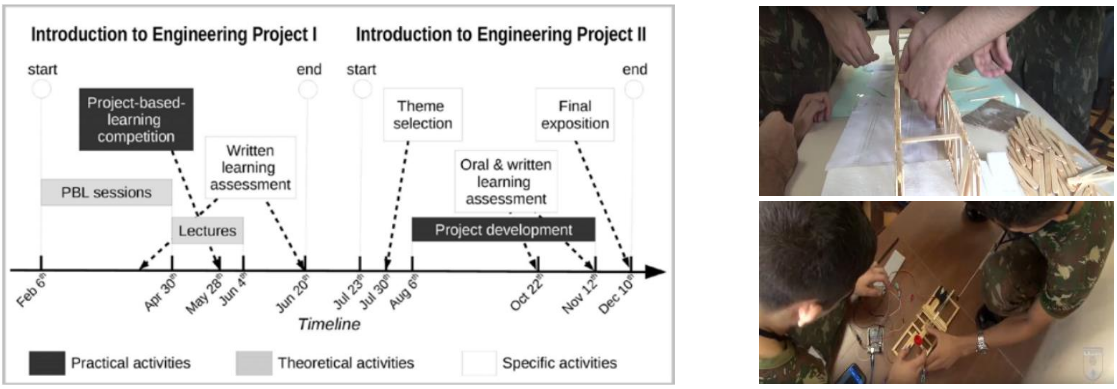

Figure 1. IEP timeline and IEP academic projects

Table 3. Teaching plan - Introduction to Engineering Project I.

DIDACTIC UNIT I - BEST PROJECT MANAGEMENT PRACTICES PRACTICES		
Teaching methodology: PBL - Project Based Learning (active learning). ***Learning assessment***: evaluation of the active method used in each class.		
Subjects	Specific objectives	Duration
1. Basic concepts of project management.	- Use the project management language. - Know the set of PMBOK best practices.	3 hours
2. Environment where projects take place.	- Know the main organizational structures of project offices.	3 hours
3. Integration management	- Know the main integrative processes of project management.	3 hours
4. Scope management.	- Describe the main tools and artifacts of project scope planning.	3 hours
5. Time management.	- Apply the main time management tools applied to project management.	3 hours
6. Risk management.	- Understand risk management and its main tools.	3 hours
7. Cost management.	- Understand the challenges of mounting costs and their relationship to other project activities.	3 hours
8. Quality management.	- Understand the meaning of quality management for project management.	3 hours
9. Resource and acquisitions	- Understand the importance of resource management and acquisitions for project management.	3 hours
10. Communications management.	- Describe the communications tools and challenges for the project.	3 hours
DIDACTIC UNIT II - PROJECT MANAGEMENT IN PRACTICE		
Teaching methodology: lectures will be given by people specialized in each area. ***Learning assessment***: Analysis of the oral and written presentation of the project report.		
Subjects	Specific objectives	Duration
1. Application of projects in the real world.	- Understand, through real cases conducted by experts, that the techniques studied in the classroom are useful, applied and are responsible for the success of projects.	3 hours
2. Preparation of scientific papers and texts.	- Know basic concepts of the scientific method and understand how this affects the construction of the scientific text.	3 hours
3. Making good presentations.	- Know the main techniques for oral presentations	3 hours
DIDACTIC UNIT III - COMPETITION AND CHALLENGE BETWEEN GROUPS		
Teaching methodology: PBL - Project Based Learning (active learning). ***Learning assessment***: evaluation of the active method used in each class and the		
Subjects	Specific objectives	Duration
1. Execution of the competition project selected.	- Practice: project management skills, project report building and teamwork through one-time project execution quickly.	6 hours

In 2018, the practical activity of IEP (Figure 1) was the competition of popsicle-stick bridges, following the specifications provided by the teaching team. In 2019, the practical activity of IEP was the competition of catapult controlled by Arduino. In both projects the students following the specifications provided by the teaching team.

For example, Table 3 shows the teaching plan of the discipline Introduction to Engineering Project I. Such discipline is typical and recommended by the CDIO.

Standard 5 (design and implement experiences)

The Mechanical Engineering program decided to include two design-build disciplines. One in the 6th and 7th periods, called Initiation to Research (IR), and another in the 9th and 10th periods, denominated Final Project of Course (FPC). This decision was based in the successful academic experience at Linköping University – LiU (Svensson & Gunnarsson, 2012). At LiU there are three design-build disciplines. Similarly, IME's mechanical engineering has three such disciplines: IEP, IR and FPC. These activities are encouraged by the new NCGs (Article 6th, Paragraphs 2nd and 3rd). In both disciplines IR and FPC, students use previously learned project methodologies and perform activities to properly meet project requirements within the established deadlines.

In 2018 an experimental design-build activity for IR course was offered to the mechanical engineering students that was a competition for Aerodesign (Figure 2).

Figure 2. Aerodesign design-build academic experience.

The proposed design had simple requirements, such as maximum span length, maximum payload for in-flight transport, deadline for flight test, and final written and oral presentation. For FPC, the “Integration Seminar between IME and Brazilian Defense Industry” has been inserted since 2015 in the IME´s calendar. From this event many design-build projects are being proposed for the FPC course so that students can solve real industry engineering problems, providing better opportunities for developing IME students' skills and competencies. With these different activities, it was possible to perceive the enthusiasm, the application of the theoretical concepts learned in the conception and construction of the prototype, the organization for teamwork and, most importantly, the consolidation of the mechanical engineering learning.

Standard 6 (engineering workspaces)

The mechanical engineering laboratories have space and resources for the development of practical activities and projects. Being multidisciplinary spaces used by all engineering. The implementation of the CDIO initiative in the undergraduate mechanical engineering courses of IME provided several important aspects for this Department. Improvement of laboratories within the scope of the new Program Pedagogical Project. About eight hundred thousand dollars were invested in the restructuring of the spaces and the purchase of equipment. Here are some improvements in the workspaces of the mechanical engineering course at IME: new didactic stands for innovative academic activities in the Engines Laboratory; new didactic benches for academic activities integrated in the Thermoscience Laboratory; new subsonic wind tunnel for the Aerodynamics Laboratory; new Industrial Robotics and Defense Laboratory; complete reform of the staff room; and replacing classroom furniture.

Standard 7 (integrated learning experiences)

Integrated learning experiences are implemented in courses across the curriculum. In IME mechanical engineering integrated learning experiences are called complementary activities. Complementary activities are usually performed outside of class time, whether provided for in the academic calendar, being compulsory or voluntary and developed individually or by groups of students.

The course curriculum highlights the inclusion of the themes of Professional Ethics and Human Rights in the Armed Forces, under the perspective of International Humanitarian Law, as well as the National Curriculum Guidelines for the Education of Ethnic-Racial Relations and for the Teaching of Afro-Brazilian and Indigenous History and Culture, through activities listed here, as well as subjects regularly included in the IME military training curriculum: Languages Project; Directed Study; Operation Ricardo Franco (ORF) in Amazon region; Integration IME industries event; Humanistic Vision Cycle; Technical Visits to Engineering Military Organizations; Technical Visits to Companies and Engineering Research Centers; Scientific Initiation; IME Action - community entrance exam project; Academic Engineering Competitions; IME student exchange; and Supervised Internship and Professional Practice.

Standards 8, 9, 10 (active learning and faculty enhancement)

The Military Institute of Engineering has been investing since 2015 in the preparation of faculty to apply active learning in their classes. There are currently several academic activities at IME where teachers explore various active learning methodologies in their classes. The active learning methodologies reported by these teachers are PBL, peer review, flipped classroom and jigsaw.

At the Military Institute of Engineering there is the Pedagogical Update and School Administration Internship (PUSAI). PUSAI was just an annual meeting to show new teachers IME standards and the functioning of the academic system. Experiences at Linköping University and KTH University have shown the need to change and make better use of PUSAI (Gunnarsson, Herbertsson, & Örman, 2019). In this way, it was created the opportunity for teachers to upgrade through the complete restructuring of the PUSAI. Contents were inserted for correct application of active learning methodologies (PBL, flipped classroom, etc.). Such methodologies provide students with experiences oriented to the development of skills and competences foreseen in the learning of the respective course. The restructuring of PUSAI has scope for all IME faculty and more meetings have been included in the institute's official academic calendar. There are currently about 12 meetings for PUSAI. At the restructured PUSAI there are lectures, workshops and hands-on teaching and motivating faculty to adopt best teaching practices and active learning in their classes.

Furthermore, the Military Institute of Engineering performs actions so that faculty can develop personal, interpersonal, product, process, and system building skills. Following are the main actions: Journey IME integration with Defense Segment Companies; and agreements and registrations with companies and educational institutions. The companies and IME are committed to leading and guiding the different end-of-course projects, proposing topics of mutual interest. This synergy has provided new learning experiences and the opportunity for faculty to guide work with real engineering problems by developing the competencies and skills constant at CDIO Syllabus.

Standard 11 (learning assessment)

Most IME courses were assessed by written tests, with a few exceptions. With the ideas of CDIO approach implementation, it occurred an adapt student assessment. The direction was the assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge. This way, the assessment methods were updated for the laboratory and design-build courses. The following IME evaluation standards have been updated: Internal Standards of Special Works, Internal Standards for Learning Measures and Internal Standards for the Assessment of Experimental Disciplines, were updated and adapted. Currently, at the time of assessment of laboratory and design-build courses, teachers fill out forms that assess the competencies and skills predicted in the learning outcomes of the course. This evolution provided more interesting works and aspects of student development that were not previously noticed in the Institute. There is a substantial improvement in the teaching-learning process with the change in assessment methodology and this process is still in development. This was beneficial for the mechanical engineering course.

Standard 12 (program evaluation)

IME has its own Institutional Evaluation Committee. The actions of this Committee are being restructured to get feedback from students, faculty, staff, program leaders, alumni, and other stakeholders to improve IME's academic activities based on the CDIO approach (Brodeur & Crawley, 2005).

To assess the current situation of the CDIO Initiative in the IME's mechanical engineering, a questionnaire was applied to the mechanical engineering course teachers (around 20 professors) to survey perceptions about the evolution of the implementation of actions related to the CDIO initiative. Figure 8 shows the result of this CDIO evolution in IME.

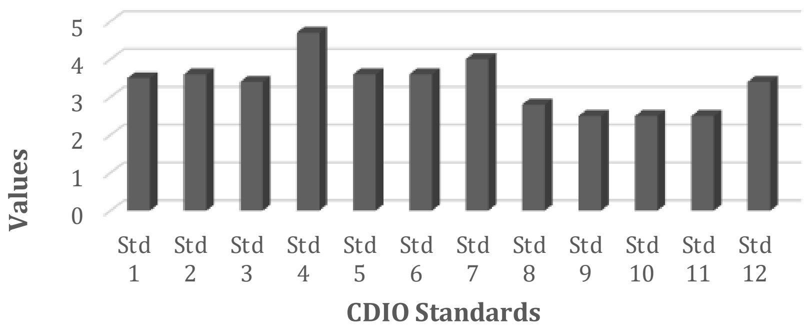

Figure 3. Shows the result of the CDIO evolution in IME's mechanical engineering.

The result in Figure 3 shows that the implementation of the CDIO approach in the mechanical engineering course at IME is progressing satisfactorily. It is perceived that there is a need to improve the preparation of teachers, which was hampered by the occurrence of the COVID-19 pandemic.

FINAL REMARKS

The application of the CDIO approach to the evolution of mechanical engineering teaching at IME was motivated by the Brazilian Army's project of innovation and entrepreneurship, by student feedback on the need for new teaching methodologies at the Institute, and by the need to adapt the pedagogical project course the new National Curriculum Guidelines. Following the CDIO Adoption Process Diagram, mechanical engineering course faculty have successfully implemented the CDIO Standards and transformed their engineering education. Feedback from faculty and students has been particularly good, with reports of classroom and laboratory improvements, different active learning practices, innovative assessment methods, and evident development of skills and competencies from the CDIO Syllabus.

Given the national academic recognition of the IME and the successful development of the CDIO implementation, there has been interest from other national educational institutions to include the CDIO approach in their respective pedagogical projects. IME faculty have been invited to give lectures and provide information about the CDIO Initiative and its implementation. Therefore, in this context of success and evolution of the teaching of mechanical engineering through the CDIO approach, the Military Institute of Engineering was accepted as a member institution of the CDIO Initiative in January 2020. In this context, the mechanical engineering of IME can contribute more effectively to improve engineering education at the Institute itself, in Brazil and in other countries around the world.

FINANCIAL SUPPORT ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support by the Brazilian Army.

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