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THE CDIO APPROACH TO DESIGN EDUCATION IN MECHANICAL ENGINEERING

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Abstract. *Mechanical engineers are responsible for creating new products and processes that serve society, with the concern to use those of available resources in an intelligent and sustainable way. In the life cycle of products, processes, and systems, in all their phases, modern engineers are involved, defining the scope of the project, helping to create the concept, and incorporating technology and innovation. To conceive, design, implement and operate products, processes and systems, proactive engineers work in teams and communicate effectively. They think creatively and critically, act responsibly, and use a range of other personal and professional skills. In this context, higher education in engineering must propose a teaching-learning environment that turns students into modern and effective engineers, capable of being technically specialists, socially responsible and inclined to innovate. To achieve these goals, universities must better prepare students through systematic reform of engineering education. The objective of this paper is to present the implementation of the engineering education approach called Conceive-Design-Implement-Operate (CDIO) in the Mechanical Engineering undergraduate course. The implementation of the CDIO approach 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 to the modern engineer. In addition, the CDIO approach is a methodology aligned with the proposals of the new Brazilian National Curriculum Guideline (DCN) for engineering courses. The implementation is shown through a case study involving the undergraduate course in mechanical engineering at Military Institute of Engineering (IME) and the initial results of this implementation demonstrate an increase in students' motivation, innovation and problem solving in new academic activities of practical and active learning.*

Keywords: *CDIO approach, constructive alignment, academic innovation.*

1. INTRODUCTION

Technological and scientific knowledge is advancing rapidly and undergraduate course in mechanical engineering must prepare professionals to solve the demands of modern society and industry.

In Brazil, for projects and services involving mechanical engineering to have competitiveness and innovation in the international scene, it is necessary to graduate mechanical 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 (DCNs) for engineering courses (Brazil, 2019b).

According to the National Education Council Report (Brazil, 2019a), the new DCNs 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 (PPCs) 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 DCNs in engineering courses:

● Involvement of professors and managers in the process of preparing new PPCs, 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 DCNs;

● 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;

● Permanent interaction between academia and industry, all undergraduate degree in engineering.

The new DCNs proposals are aligned with the needs desired by the industry and society, regarding the modern engineer profile (Crawley et al., 2014).

A mechanical engineering undergraduate can be considered an excellent environment for the development of new academic teaching-learning activities, as it has diversified areas of expertise, such as Thermosciences, Machine Design, Manufacturing Processes, Project Management, and others.

However, the academic questioning of the various engineering undergraduate courses is how to carry out the necessary adaptation to the new DCNs 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 et al., 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 DCNs, 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 (Rezende et al., 2019).

2. THE CDIO APPROACH

The CDIO approach is a pedagogical project that emphasizes engineering fundamentals in the context of conceiving, designing, implementing, and operating real-world systems and products. CDIO uses active learning methodologies, such as teamwork, flipped classroom and problem-based learning (PBL), aiming to improve the teaching of engineering students in theoretical and technical knowledge, in addition to providing important personal and interpersonal skills to the graduate. In addition, the CDIO initiative provides resources for university professors to improve their teaching skills.

The CDIO concept was originally conceived at the Massachusetts Institute of Technology in the late 1990s. In 2000, MIT, in collaboration with three Swedish universities - Chalmers University of Technology, Linköping University and the Royal Institute of Technology - formally founded the CDIO Initiative. It has become an international collaboration, currently with around 180 universities around the world adopting the same framework. In Brazil there are 9 universities that belong to the CDIO Initiative: Military Institute of Engineering (IME), - Pará State University Center (CESUPA), School of Engineering of Lorena, University of São Paulo (EEL-USP), Salesian University Center of São Paulo (UNISAL), Federal University of Grande Dourados (UFGD), State University of São Paulo Julio de Mesquita Filho (UNESP), Federal University of Santa Maria (UFSM), University Center Toledo Araçatuba (UNITOLEDO) and University of Vale do Taquari (UNIVATES). Figure 1 shows the distribution of engineering education institutions that are members of the CDIO Initiative (CDIO, 2021).

Figure 1. Map of the current CDIO member schools (CDIO, 2021).

The objective of higher education is to educate students to become effective engineers, capable of participating in and eventually leading aspects of conception, design, implementation and operating systems, products, processes, and projects. Currently, there is a difficulty in reconciling two needs in engineering education. On the one hand, there is a need to transmit the growing theoretical and technological knowledge that undergraduate students must master. On the other hand, there is growing recognition that engineers must possess important personal and interpersonal skills. This is the same difficulty (Cerqueira et al., 2016) that many Brazilian Engineering Education Institutions have to adapt to the new National Curriculum Guidelines (DCN). In recent surveys, North American and European companies indicated that the main skills and qualities desired to graduate from an Engineering course are verbal and written communication, ethics in activities, teamwork, ability to manage projects and proactivity (Kontio, 2017).

In this context, the CDIO approach is a proposal for engineering education to be the integration of theoretical and technological knowledge learning with the development of essential skills and abilities for the engineer and his work. This integrated proposal must be well defined and applied in the Pedagogical Project of the undergraduate course (PPC).

The CDIO approach has its conceptual foundations in the idea of constructive alignment. Constructive alignment starts with the notion that the learner constructs his or her own learning through relevant learning activities. The teacher's job is to create a learning environment that supports the learning activities appropriate to achieving the desired learning outcomes. The key is that all components in the teaching system - the curriculum and its intended outcomes, the teaching methods used, the assessment tasks - are aligned to each other. All are tuned to learning activities addressed in the desired learning outcomes. The learner finds it difficult to escape without learning appropriately (Biggs, 1996). Summarizing, as shown in Figure 2, for students to achieve the learning outcomes of a course, these defined outcomes must also be present in the final assessments, as well as the during the course activities. In this way, the learning outcomes, assessments and learning activities are aligned.

Figure 2. Constructive alignment between all three elements. (Biggs and Tang, 2011).

In order to carry out the constructive alignment in the creation of a new pedagogical project for an engineering course, the CDIO approach structure is composed of the CDIO Syllabus and the CDIO Standards.

2.1 CDIO Syllabus

The CDIO Syllabus is the cornerstone of CDIO. It offers rational, complete, universal and generalizable goals for undergraduate engineering education.The CDIO Syllabus is the set of core competencies, skills, and attitudes that research institutes, companies and industries want for a future generation of young engineers, according to surveys carried out by the founders of the CDIO Initiative (Crawley, 2001).

Whether in its complete version or a condensed version, the CDIO Syllabus focuses on personal, interpersonal and system building skills, and leaves a placeholder for the disciplinary fundamentals appropriate for any specific field of engineering. It complements and significantly expands on Accreditation Board for Engineering and Technology - ABET's criteria (ABET, 2021).

With rationale, detail and broad applicability, the CDIO Syllabus' principal value is that it can be generalized to serve as a model from which any university's engineering programs may derive specific learning outcomes. In 2011 a revised and updated CDIO Syllabus was presented, the CDIO Syllabus 2.0. The updates and revisions were based on comparisons with the UNESCO Four Pillars of Learning, with which it is aligned at a high level, national accreditation and evaluation standards of several nations and input received over the last decade since the Syllabus was originally written in 2001. Table 1 shows the CDIO Syllabus (CDIO, 2021).

2.2 CDIO Standards

The CDIO Initiative uses 12 standards that serve as a guideline for the reform and evaluation of new pedagogical course designs (PPCs), containing references and goals with worldwide application and providing an engineering undergraduate course with continuous improvement. The CDIO Standards (Brodeur and Crawley, 2005) were developed in response to program leaders, alumni and industry partners who wanted to know how they would recognize CDIO programs and their graduates. Table 2 shows the 12 CDIO Standards.

Table 1. CDIO Syllabus at the second level of detail.

First level	Second Level
1. Disciplinary knowledge (Learning to know)	1.1 Knowledge of underlying mathematics and science 1.2 Core engineering fundamental knowledge 1.3 Advanced engineering fundamental knowledge, methods, and tools
2. Personal and professional skills and attributes (Learning to be)	2.1 Analytical reasoning and problem solving 2.2 Experimentation, investigation, and knowledge discovery 2.3 System thinking 2.4 Personal skills and attributes 2.5 Professional skills and attributes
3. Interpersonal skills (Learning to live together)	3.1 Teamwork 3.2 Communications 3.3 Communication in a foreign language
4. Conceiving, designing, implementing, and operating systems in the enterprise, societal and environmental context - the innovation process (Learning to do)	4.1 External, societal, and environmental context 4.2 Enterprise and business context 4.3 Conceiving, system engineering, and management 4.4 Designing 4.5 Implementing 4.6 Operating

Table 2. CDIO Standards (Crawley et al., 2014).

CDIO Standard	Summary
1. The context	Adoption idea that product, process, and system lifecycle development and deployment (Conceive-Design-Implement-Operate) are the engineering education context.
2. Learning outcomes	Specific, detailed learning outcomes for personal and interpersonal skills; and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders.
3. Integrated curriculum	A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills.
4. Introduction to engineering	An introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills.
5. Design-implement experiences	A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level.
6. Engineering workspaces	Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning.
7. Integrated learning experiences	Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills.
8. Active learning	Teaching and learning based on active and experiential learning methods.
9. Enhancement of faculty competence	Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills.
10. Enhancement of faculty teaching competence	Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning.
11. Learning assessment	Assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge.
12. Program evaluation	A system that evaluates programs against these standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement.

The twelve CDIO standards address program philosophy (Standard 1), curriculum development (Standards 2, 3 and 4), design-build experiences and workspaces (Standards 5 and 6), new methods of teaching and learning (Standards 7 and 8), faculty development (Standards 9 and 10), and assessment and evaluation (Standards 11 and 12).

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

The mechanical engineering undergraduate course in the Military Institute of Engineering (IME) has two specialties: Mechanics and Armament Engineering and Mechanics and Automotive Engineering. In both undergraduate courses are present the basic contents for mechanical engineering, such as Thermodynamics, Fluid Mechanics, Dynamics, Solid Mechanics and Machine Projects. For Armament Engineering there are disciplines involving ballistic phenomena and for Automotive Engineering there are disciplines involving the vehicular dynamics.

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 and are the same for all ten IME's programs. Only after the fourth semester mechanical engineering students will have contact with the specific content. Each mechanical engineering program has 3,600 hours of activities in engineering education.

The mechanical engineering at IME, to improve and transform its PPC, must agree with the new National Curriculum Guidelines (DCNs) of the Ministry of Education (BRAZIL, 2019b). Thus, a study was carried out to assess whether the academic premises of the new DCNs (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 DCNs. Table 3 shows the comparison topics.

Table 3. Alignment of the propositions for the PPCs of the new DCNs with the CDIO Standards.

Propositions for PPCs by DCNs	DCN's Articles (BRAZIL, 2019a)	CDIO Standards
Induction of innovative institutional policies	DCN report (BRAZIL, 2019b)	CDIO as context
	Art. 6th , Parag. 12th; Art. 17th	Program evaluation
Focus on teaching through skills development	Art. 6th	Integrated curriculum
	Art. 3rd, 4th , and 5th	Learning outcomes
Emphasis on managing the learning process	Art. 6th , Parag. 4th	Introduction to engineering
	Art. 6th , Parag. 7th, 8th and 9th	Integrated learning experiences
	Art. 13rd , Parag. 1st, 2nd, and 3rd	Learning assessment
	Art. 6th , Parag. 1st	Engineering workspaces
Relationship strengthening with different organizations	Art. 6th , Parag. 2nd and 3rd	Design-implement experiences
Innovative teaching methodologies	Art. 6th , Parag. 6th	Active learning
Valuing faculty training	Art. 6th , Parag. 10th	Enhancement of faculty competence
	Art. 14th , Parag. 1st	Enhancement of faculty teaching competence

The result shown in Table 3 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 DCNs. The second column of table 3 shows the articles of the DCNs and their respective paragraphs that demonstrate, in a regulatory manner, the alignment of the CDIO with the new DCNs.

Thus, to implement the approach (Ulloa et al., 2014) the adoption process proposed by the CDIO Initiative (CDIO, 2021) was used, as shown in the diagram in Figure 3.

The process begins with the involvement of the academic staff (professors and students) to update the pedagogical project of the course (PPC) through the CDIO approach, in an innovative and motivating context for engineering education (Standard 1). Then, the learning outcomes are defined, containing the skills and competences associated with the CDIO Syllabus (Standard 2). These two steps establish the context, program objectives, and specific learning goals (Ulloa et al., 2014; CDIO, 2021).

The next step is to establish the current stage of the current PPC by evaluating the undergraduate course in four areas: curriculum, workspaces, teaching and learning methods, and assessment methods.

In this way, in each of these four areas, faculty can identify areas for improvement and design aspects of the PPC to achieve the learning outcomes. This leads to activities that meet Standards 3-8 and 11 and 12. The columns in the implementation flow diagram are loosely aligned with the four areas: curriculum, workspaces, teaching and learning, and assessment.

At the end of the flowchart in Figure 3, after the assessment and planning of the previous steps, there will be a need to implement or strengthen faculty improvement in CDIO practices and in new teaching, learning and assessment methodologies (Standards 9 and 10).

Through this organization proposed in the diagram in Figure 3, activities were started to adapt the PPCs of the mechanical engineering courses at IME to the new DCNs, through the CDIO approach and its Standards. The following subsections present the actions taken to adapt the courses to the CDIO Standards and, consequently, to the new DCNs.

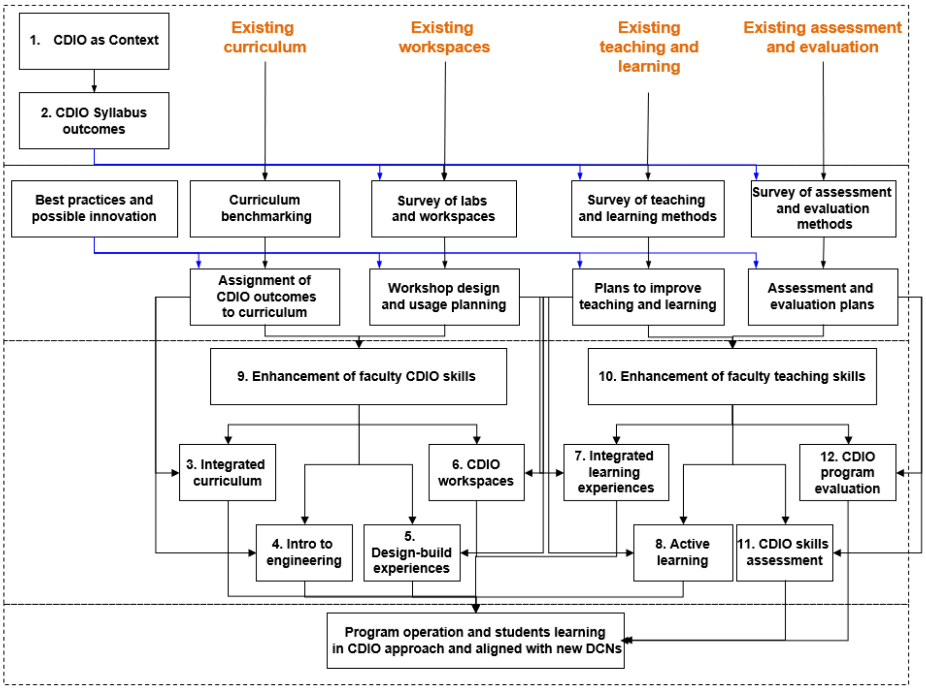

Figure 3. Adoption process diagram (Ulloa et al., 2014; CDIO, 2021).

3.1 Standard 1 (the context) and the new DCNs

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 (CONFEA), DCNs and CDIO Syllabus (Crawley et al., 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 in general.

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

According to the CDIO implementation process diagram (CDIO Initiative, 2017), 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 PPC (CDIO Standard 2). 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. For mechanical engineering higher education, the Brazilian law determines the learning outcomes are are in accordance with the DCNs (Articles 3rd, 4th , 5th) for engineering courses (Brazil, 2019b). To exercise the mechanical engineer profession, the Federal Council of Engineering and Agronomy (CONFEA, 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 (Brazilian Government, 2002) and by the Federal Council of Engineering and Agronomy (CONFEA, 2005), present a strong similarity. In this way, Table 5 correlates the demands of National Guidelines and CONFEA with the skills and knowledge proposed by the sections of the CDIO Syllabus.

Table 5 shows that the CDIO Syllabus addresses all the needs of Brazilian education laws and the exercise of engineering activity in companies (CONFEA 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 et. al., 2014). The need to improve engineering education in Brazil through an integrated curriculum is present in Article 6th of the new DCNs.

Table 5. Correlation of competences between the Brazilian aspects and the CDIO.

Competencies established by the DCNs and by CONFEA		***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		

3.3 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 DCNs (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 et al., 2019). During these two semesters, the practices become increasingly complex, always considering the student's level and knowledge. Figure 4 shows IEP I & II.

In 2018, the practical activity of IEP 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. Figure 4 shows these activities.

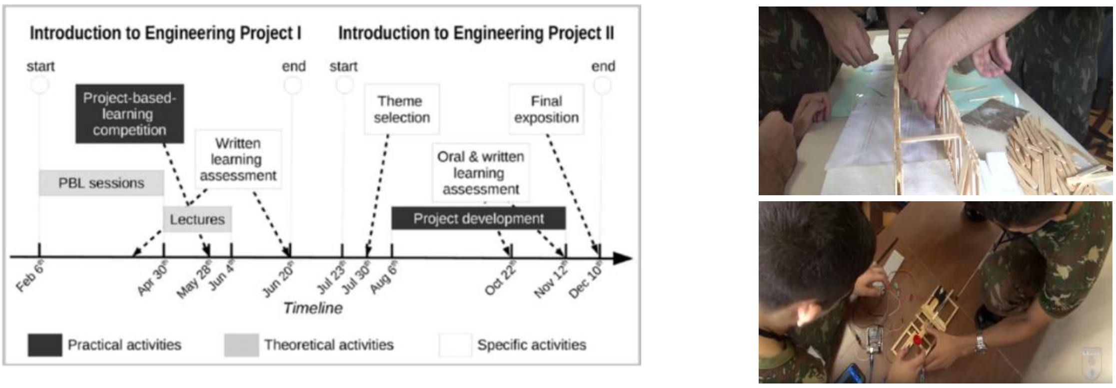

Figure 4. IEP timeline and IEP academic projects (Passos et al., 2019).

For example, Table 6 show the teaching plan of the discipline Introduction to Engineering Project I. Such discipline is typical and recommended by the CDIO. Other examples of academic practices and disciplines can be found on the CDIO website (CDIO, 2021).

Table 6. 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	HOURS/CLASS
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. Gestão de recursos e aquisições	- Compreender a importância da gestão de recursos e aquisições para a gestão de projetos.	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	HOURS/CLASS
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 important 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 innovation.		
SUBJECTS	SPECIFIC OBJECTIVES	HOURS/CLASS
1. Execution of the competition project selected.	- Practice: project management skills, project report building and teamwork through one-time project execution quickly.	6 hours

3.4 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 (IP), and another in the 9th and 10th periods, denominated Final Project of Course (PFC). This decision was based in the successful academic experience at Linköping University – LiU (Svensson and Gunnarsson, 2012). At LiU there are three design-build disciplines. Similarly, IME's mechanical engineering has three such disciplines:

IEP, IP and PFC. These activities are encouraged by the new DCNs (Article 6th , Paragraphs 2nd and 3rd). In both disciplines IP and PFC, students will use previously learned project methodologies and will perform activities to properly meet project requirements within the established deadlines. In 2018 an experimental design-build activity for IP course was offered to the mechanical engineering students that was a competition for Aerodesign (Figure 6). 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 PFC, the "Integration Seminar between IME and Brazilian Defense Industry" has been inserted since 2015 in the calendar of the Military Institute of Engineering. From this event many design-build projects are being proposed for the PFC 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.

Figure 6. Aerodesign design-build academic experience.

3.5 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.

3.6 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.

3.7 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 (ESTAPAE). ESTAPAE 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 ESTAPAE (Gunnarson et al., 2019). In this way, it was created the opportunity for teachers to upgrade through the complete restructuring of the ESTAPAE. Contents were inserted for correct application of active learning methodologies (PBL, inverted class, 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 ESTAPAE 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 ESTAPAE. At the restructured ESTAPAE 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.

3.8 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.

3.9 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.

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.

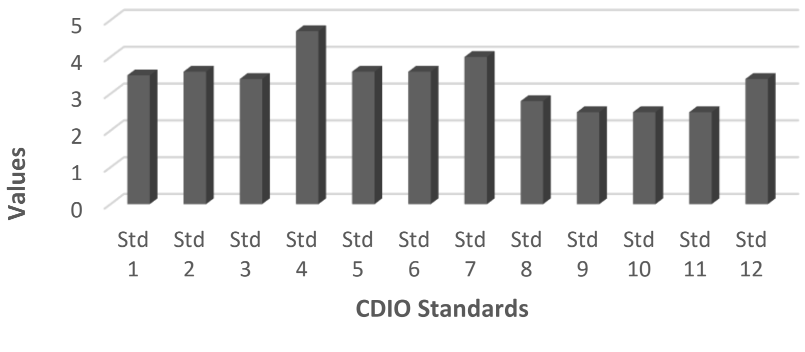

Figure 8. Shows the result of the CDIO evolution in IME’s mechanical engineering.

The result in Figure 8 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.

4. 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.

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6. RESPONSIBILITY NOTICE

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