# DEVELOPIN COMPETENCES IN ENGINEERING STUDENTS. THE CASE OF PROJECT MANAGEMENT COURSE

Dante Guerrero; Martín Palma; Gerson La Rosa

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# Developing competences in engineering students. The case of project management course

Dante Guerrero[a]*, Martín Palma[a], Gerson La Rosa[a]

[a]*University of Piura, Av. Ramón Mugica 131-Urb. San Eduardo, 20009 Piura, Perú*

**Abstract**

Education on Engineering urges of learning methodologies different to the current ones that would allow students to profile competences in accordance to the exigencies of the competitive exercise of engineering, in which they will perform the essential functions typical of the career and develop as an upright, mature, and reflective people.
Three questions are brought up in this study: Which are the basic competences that need a contemporary engineer? How can the learning of these basic competences be improved and assessed in engineering students?
The results allow to show, by comparing groups of students belonging to the course of "Direccion de proyectos en Ingenieria" (Engineering Project Management), that there exists strong evidence for improvement of basic competences: underlying science knowledge, knowledge of fundamental and advanced engineering, engineering reasoning and problem solving, systemic thinking, as well as conceiving, designing, implementing and operating systems in companies and in social context.
It is considered feasible to integrate the experience in other courses of Engineering reinforcing the tutorial role of the teacher, defining evaluation criteria of the course and identifying and assessing the improvement of competences during the learning process.



*Keywords:* Competences; Higher education engineering; CDIO

## 1. Introduction

Currently, companies and society require engineers with a wide range of knowledge and skills that would allow them to meet labor market expectations and to venture successfully in a world that is changing at a rapid pace (Ramírez, 2009) (Palma, De los Ríos, Miñán, & Luy, 2012).

To be able to meet this demand, higher education institutions urge of learning methodologies different to the current ones, in which actors and responsible parties of institutions carry out a set of activities in order to achieve the best training of future professionals (Tabares Mesa & Londoño Vélez, 1991) (Shuman, y otros, 2002).

In this context, the Education in Engineering should be more inclusive, having a body of knowledge and skills that are based in basic appropriate competences such as competences in the main subject area as well as general competences about the activity and entrepreneurial and social contexts and the understanding of characteristics of future professionals (Kans, 2012) (Astigarraga, Dow, Lara, Prewitt, & Ward, 2010) (Andersen, Yazdani, & Andersen, 2007).

The objective of the article is in first place, to describe the basic competences necessary in Engineering that allow to define the learning strategy and, at the same time, to establish assesment mechanisms in a course of Industrial and Systems Engineering at the Universidad de Piura (Perú), and then demonstrate the improvement of students' basic competences through statistical analisys that supports the conclusions presented at the end of the paper.

## 2. Basic competences in Engineering

In the typical curricula of the 90's engineering student, rarely there was the opportunity to take a real problem,

* Corresponding author. Tel.: +00-51-1-284500
*E-mail address:* dante.guerrero@udep.pe

extract its essence and apply the respective analysis that would lead to a good decision making (Dunn-Rankin, Bobrow, Mease, & McCarthy, 1998). Since then, employers and professional and technical institutions have expressed their concern about basic competences in engineering (Andersen, Yazdani, & Andersen, 2007).

Basic competences, understood as essential or important, are considered indispensibles by allowing the professional training at work in a lifetime learning. Needs to be mentioned that these basic competences are interrelated to each other, so it is more important to evaluate them as a group rather than separately, and it is expected that in the near future the credibility and the quality of educational systems will depend in their ability to promote their learning, specially those competences related to the person's integral training (Sarramona, 2002) (European Communities, 2007).

Basic competences include cognitive, technical and methodological, and their inclussion into the curricula may have several purposes: to integrate the different learning, the different types of contents and to utilize them effectively when necessary in different situations and contexts, and to guide the learning (Hecker, 1997).

In the framework of the EEES and the Bolonia process, there have been identified eight core competences for the permanent learning comprised of knowledge, skills and attitudes adequate to the context. These core competences are: Linguistic communication competence, Foreign language competences, Mathematical competence, Competence in knowledge and the interaction with the physical world, Information processing and digital competence, Social and civic competence, Cultural and artistic competence, Learning to learn competence, Autonomy and Personal initiative (Hutmacher, 2003) (European Communities, 2007).

Without doubt, it can be asserted that in the new millennium learning society, the profile of a good engineer should be based on the ability and willingness for learning, the solid knowledge of basic natural sciences and good knowledge of any field of technology, in addition to general human values (Palma, Miñán, & De los Ríos, 2011). On the other hand, the engineer has to be prepared for permanent learning, and must also have good communication and teamwork. Technical competences are not enough in today's world (Maffioli & Giuliano, 2003).

In this context of engineering, there has been developed varied necessary skills lists that are sought in modern engineers. Within the bibliography reviewed, one of the most serious papers undertaken in the definition of competences is the proposal of the Accreditation Board of Engineering and Technology (ABET) that shows the indispensible competences for engineers, divided in two categories: hard skills and professional skills (See Table 1) (Maffioli & Giuliano, 2003). The so-called hard skills are technical in nature, while the professional skills make the real difference between a professional and another.

Table 1. ABET criteria for students completing engineering.

| **Hard Skills** |
|---|
| (a) an ability to apply knowledge of mathematics, science, and engineering |
| (b) an ability to design and conduct experiments, as well as to analyze and interpret data |
| (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability |
| (e) an ability to identify, formulate, and solve engineering problems |
| (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. |
| **Professional Skills** |
| (d) an ability to function on multidisciplinary teams |
| (f) an understanding of professional and ethical responsibility |
| (g) an ability to communicate effectively |
| (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context |
| (i) a recognition of the need for, and an ability to engage in life-long learning |
| (j) a knowledge of contemporary issues |

On the other hand, the CDIO proposal stands out which, based on a comparative study, it is verified that this proposal is well aligned with ABET criteria (Palma, De los Ríos, Miñán, & Luy, 2012). The CDIO proposal is an initiative born at Massachusetts Institute of Technology (MIT) and the Swedish universities of Chalmers, Linköping and KTH. Currently, more than 80 institutions of more than 25 countries are participating. In the CDIO framework, learning the fundamentals and the advanced disciplinary content on engineering is promoted, in an environment with clear references to the professional practice of engineering as an adequate context for learning. The CDIO proposal has three major general objectives: mastering a deep knowledge in fundamental techniques, leadership in the creation and operation of new products, processes and systems, and to understand the importance and the strategic impact of research and the technological development in society proposed through the development of standards and of CDIO's syllabus.

The CDIO syllabus defines competences that students should have when completing their training as engineers. These are the result of the confluence of the interests of all the parties involved in the engineering activity. In the definition of competences, it is used as key tool the participation through surveys of faculty, the industry, alumni, among other stakeholders. In Table 2 are competences of first and second level defined by CDIO, organized in four training areas: Technical knowledge and critical thinking, professional and personal skills, interpersonal skills and CDIO (Conceive-Design-Implement-Operate).

In the CDIO proposal, competences have greater scope, degree of precision, and include not only generic , personal and interpersonal competences that can correspond to any discipline, but also those that have been identified as typical of engineering, and that correspond to the necessary abilities to develop products and complex systems in a cooperative environment (Bragós Bardía, 2012).

In addition to comparing the CDIO syllabus with ABET, CDIO has been compared with various competences lists of industrial companies, various national (UK-SPEC, Swedish national engineering degree requirements) and international (European EUR-ACE framework standards for accreditation of engineering programs) standards, resulting in all cases that the CDIO syllabus offers a more comprehensive framework (Crawley, Malmqvist, Lucas, & Brodeur, 2011).

This allows the CDIO proposal to be an important reference for defining basic competences pertinent to an engineering program, and for that same reason the CDIO syllabus will be the basis for the design and assessment for improving basic competences on engineering in the course of projects at the Universidad de Piura.

Table 2. Objectives of first and second level of CDIO syllabus.

| | | | |
|---|---|---|---|
| **1** | **Technical knowledge and reasoning** | **3** | **Interpersonal skills: teamwork and communication** |
| 1.1 | Necessary basic underlying knowledge in sciences | 3.1 | Teamwork |
| 1.2 | A body of knowledge of Fundamental Engineering | 3.2 | Communication |
| 1.3 | Knowledge of the fundamentals of Advanced Engineering | 3.3 | Mastery of a foreign language |
| **2** | **Skills and personal and professional attributes** | **4** | **Conceive, design, implement, and operate systems in the business and social context** |
| 2.1 | Engineering reasoning and problem solving | 4.1 | The social and external context |
| 2.2 | Experimentation and knowledge discovery | 4.2 | The context of business and company |
| 2.3 | Systemic thinking | 4.3 | Conceive |
| 2.4 | Skills and personal attitudes | 4.4 | Design |
| 2.5 | Professional skills and attitudes | 4.5 | Implement |
| | | 4.6 | Operate |

## 3. Project Management Course

The **objective** set for the course is to achieve that, when completing, the student can be able to: formulate and evaluate projects, run processes, have knowledge of Project Management competences, and to perform managerial roles in identifying real market needs.

The technical **content** of the course consists of 10 chapters (See table 3) designed from the "Bases para la Competencia de Dirección de Proyectos NCB Versión 3.1" (IPMA, 2009) (Basis for NCB Project Management Competence Version 3.1) and the "Guía de los Fundamentos de la Dirección de Proyectos 4ta Edición" (PMI, 2008) (Guide of Project Management Fundamentals 4th Edition). The content provides a framework for the practice of project management for the development of end products, services, systems, among others. Together, the course's content is proposed to encompass competences expressed in the first category of CDIO syllabus: Technical knowledge and reasoning in relation to the project management course.

Table 3. Content of the course

| Chapter | Content |
|---|---|
| 1 | Teoría General del Proyecto (General Theory of the Project) |
| 2 | Metodología de la Formulación de Proyectos (Project Formulation Methodology) |
| 3 | Metodología de la Evaluación de Proyectos (Project Assesment Methodology) |
| 4 | Las Competencias en la Dirección de Proyectos (Competences in Project Management) |
| 5 | Grupo de Procesos de Iniciación y Competencias (Group of Initiation Processes and Competences) |
| 6 | Grupo de Procesos de Planificación y Competencias (Group of Planning Processes and Competences) |
| 7 | Grupo de Procesos de Ejecución y Competencias (Group of Implementation Processes and Competences) |
| 8 | Grupo de Procesos de Seguimiento y Control y Competencias (Group of Follow-up and Control Processes and Competences) |
| 9 | Grupo de Procesos de Cierre y Competencias (Group of Closing Processes and Competences) |
| 10 | Revisión de las Certificaciones a nivel mundial (Review of Global Certifications) |

On the other hand, competences corresponding to categories 2, 3 and 4 of the CDIO syllabus intend to be covered through a series of activities, methodologies promoted with the use of technologies that are part of the course strategy.

The **course strategy** is a mixed approach of teaching strategies, whose result is the conjunction of active methodologies, whose dynamics is related to Project-based learning (PBL), collaborative work and the new technologies, methodologies presented in different researches (Galeana, 2006) (NAF, 2011) (Bell, 2010).

In the course, students carry out projects that require to be familiarized with current problems and new professional trends. Here, students determine key factors of their projects through engineering reasoning and problem solving, systemic thinking and knowledge of the social context, external, of businesses and companies, skills that characterize practices of modern engineers. In addition, projects allow students develop interpersonal skills for teamwork and communication with government officials, community groups or companies in the region, all actors with whom the student must interact once he/she becomes a professional.

In the strategy, it is important to highlight the teacher mentoring support, who should facilitate the environment for an active learning through management software licenses and access to the virtual platform MOODLE, and must also include activities as assigning certified instructors in Project Management, personalized advice, liaison with specialists from the University, and provide support to achieve contacting regional companies, government organizations and community groups. The teacher should provide easiness for learning orientation, additionally train key skills that the student requires, provide feedback through the assessment of project progress, provide examples of good practices during the development of example classes, conduct workshops that allow the student to commit, promote research, and distribute knowledge and experiences acquired. Special care and time should be given in conducting the workshop to generate ideas that allow developing good projects.

This workshop aims to introduce the student experiences of entrepreneurial projects, of research, social, and of sustainable development. Also, methodologies and mentoring are provided to direct the individual and group creative effort important to identify the possibilities that will allow building a good project.

It is important that **assessment methods** match with expected learning results, and to use different methods to allow eliminating biases in evaluating the students' skills. For that same reason, the assessments designed for the course of projects are classified in three types: exams, the semester project and the participation.

**Exams** are written and performed virtually using the MOODLE platform. Questions developed are direct of multiple choices related to the objectives of first and second level of CDIO syllabus. These exams represent 20% of total evaluation.

The **Semester Project** is in a group. Experience has shown that it is preferable to have 5 or 6 people per group. Formation of groups and the topic of the Project are free. Approval of the project conditions the approval of the course, and it represents 60% of the total assessment. Looking to enhance the teacher mentoring role, an instructor is assigned to each group. Instructors have a diploma in PMI, and are certified by IPMA in Project Management. They are in charge for resolving questions about the content of the course, provide advice in the formulation, design and implementation of the Project, and assist the project team in the development of all management deliverables in the final report and in the presentation.

**Participation** is continuous, related directly with participation in: workshops, the Project, formal evidences in acquiring competences, and the formal presentation of deliverables: Project Idea, Document of Creation, Scope Concept, Project Management Plans and Closing Report. The participation represents 20% of total evaluation.

For the assessment of the semester project and participation, a series of criteria previously defined are made, which students must be clear about and know in advance.

Table 4 shows specific learning objectives, assessment methods and examples of CDIO results of the Project Management course.

Table 4. Results and learning assessment methods in the course

| Learning objectives of the course | Assessment Method | CDIO results (examples from) |
|---|---|---|
| Develop management roles in identifying real market needs, formulation and project assessment, and project management process and competences. | Deliverables | 3.1 Teamwork<br>3.3 Mastering of a foreign language<br>4.1 Social and external context.<br>4.2 The context of businesses and companies<br>4.3 Conceive<br>4.4 Design<br>4.5 Implement<br>4.6 Operate |
| Develop the basis of technical competences knowledge, behavioral and contextual for Project Management. | -Written exams<br>-Self assessment | 1.1 Necessary basic underlying knowledge in Sciences.<br>1.2 A body of knowledge of fundamental Engineering.<br>1.3 Knowledge of Advanced Engineering Fundamentals. |
| Students need to be able to consolidate the project design in reference to its formulation and assessment, knowledge areas, and the project's life cycle. | -Progress reports<br>-Delivery and presentation of final report. | 2.1 Engineering reasoning and problem solving.<br>2.2 Experimentation and knowledge discovery.<br>2.3 Systemic thinking.<br>2.4 Skills and personal attitudes.<br>2.5 Professional skills and attitudes.<br>3.2 Communication. |

As shown in column 3 of Table 4, the course evaluates several of the competences of the CDO syllabus. Basic and advanced knowledge of Project Management through written exams, the ability to work in teams and CDIO competences (conceive, design, implement and operate) by assessing deliverables throughout the project's life cycle, and communication, skills and personal and professional attitudes through the presentation of the final project.

## 4. Methodology of Analysis

To asses basic competences, three questions of research are presented: **(1)** Do students of 2011 and 2012 start from the same competences level when beginning the course? (2) Did students of 2011 and 2012 reach the same competences level when ending the course? and (3) Is there an improvement of students' competences when beginning and ending the course?

For each of these questions, the null hypothesis with its respective alternative hypothesis is formulated:

Table 5: Hypothesis approach

| **(1)** Do students of 2011 and 2012 start from the same competences level when beginning the course? | **(2)** Did students of 2011 and 2012 reach the same competences level when ending the course? | **(3)** Is there an improvement of students' competences when beginning and ending the course? |
|---|---|---|
| $H_0$: CB $(2011)_I$ = CB $(2012)_I$<br>$H_1$: CB $(2011)_I$ < CB $(2012)_I$ | $H_0$: CB $(2011)_F$ = CB $(2012)_F$<br>$H_1$: CB (2011)F < CB $(2012)_F$ | $H_0$: CB $(2011\text{-}12)_I$ = CB $(2011\text{-}12)_F$<br>$H_1$: CB $(2011\text{-}12)_I$ < CB $(2011\text{-}12)_F$ |

**Note:** "CB=Basic competence", "Pr($|H_1|$ > $|H_0|$) < 0.05 confirm $H_1$", "Pr($|H_1|$ > $|H_0|$) > 0.05 confirm $H_0$"

For statistical analysis, we used the "t student" test using the Stata/IC 11.1 software evaluating the hypothesis set for each of the 17 competences of the second level of CDIO syllabus.

## 5. Results

Table 6: Statistical analysis for skills improvement

| | Competence | Final Score 2011 | (improvement %) 2012 | Global | Pr(\|H1\| > \| H0\|) (1) | (2) | (3) |
|---|---|---|---|---|---|---|---|
| **1** | **Technical knowledge and reasoning** | | | | | | |
| 1.1 | Necessary basic underlying knowledge in Sciences | 5.1(↑24%) | 5.2 (↑16%) | 5.2(↑19%) | 0,009 | 0,971 | 0,00 |
| 1.2 | A body of knowledge of Fundamental Engineering | 4.8(↑23%) | 5.0 (↑18%) | 4.9(↑20%) | 0,050 | 0,910 | 0,00 |
| 1.3 | Knowledge of Advanced Engineering fundamentals | 5.5(↑24%) | 5.6 (↑18%) | 5.6(↑20%) | 0,046 | 0,991 | 0,00 |
| **2** | **Skills and personal and professional attributes** | | | | | | |
| 2.1 | Engineering reasoning and Problem Solving | 5.0 ↑19%) | 5.0 (↑15%) | 5.0 (↑17%) | 0,097 | 0,703 | 0,00 |
| 2.2 | Experimentation and knowledge discovery | 5.8 (↑16%) | 5.3 (↑10%) | 5.5 (↑12%) | 0,506 | 0,021 | 0,00 |
| 2.3 | Systemic thinking | 4.8 (↑19%) | 4.9 (↑16%) | 4.9 (↑17%) | 0,080 | 0,929 | 0,00 |
| 2.4 | Skills and personal attitudes | 5.3 (↑18%) | 5.3 (↑12%) | 5.3 (↑14%) | 0,010 | 0,485 | 0,00 |
| 2.5 | Professional skills and attitudes | 5.2 (↑17%) | 5.2 (↑13%) | 5.2 (↑15%) | 0,101 | 0,565 | 0,00 |
| **3** | **Interpersonal skills: work team and communication** | | | | | | |
| 3.1 | Work team | 5.3 (↑16%) | 5.2 (↑13%) | 5.2 (↑14%) | 0,220 | 0,508 | 0,00 |
| 3.2 | Communication | 5.2 (↑19%) | 5.3 (↑14%) | 5.2 (↑16%) | 0,028 | 0,721 | 0,00 |
| 3.3 | Mastery of a foreign language | 4.7 (↑23%) | 4.8 (↑18%) | 4.8 (↑20%) | 0,104 | 0,845 | 0,00 |
| **4** | **Conceive, design, implement, and operate systems in the company and social context** | | | | | | |
| 4.1 | Social and external context | 5.3 (↑16%) | 5.3 (↑11%) | 5.3 (↑13%) | 0,033 | 0,599 | 0,00 |
| 4.2 | Business and company context | 5.1 (↑18%) | 5.2 (↑15%) | 5.2 (↑16%) | 0,061 | 0,953 | 0,00 |
| 4.3 | Conceive | 5.0 (↑23%) | 5.2 (↑18%) | 5.1 (↑20%) | 0,024 | 0,838 | 0,00 |
| 4.4 | Projects | 4.9 (↑22%) | 5.0 (↑15%) | 4.9 (↑18%) | 0,008 | 0,902 | 0,00 |
| 4.5 | Implementation | 4.9 (↑25%) | 5.0 (↑18%) | 5.0 (↑21%) | 0,168 | 0,805 | 0,00 |
| 4.6 | Operation | 4.7 (↑26%) | 4.8 (↑17%) | 4.8 (↑21%) | 0,002 | 0,841 | 0,00 |

Note: "Final scoring scale is 1 – 10", "improvement % = (final score – initial score)/10"

In Table 6, we note that in the third research question (3) the values are equal to 0, allowing confirming the alternative hypothesis thus asserting that there is an improvement of basic student competences when beginning and ending the course. For the first research question (1), we confirm that in some competences, the null hypothesis is accepted and in other cases is cancelled, allowing to assert that students of years 2011 and 2012 start from the same level of competence, except competencies 1.1, 1.3, 2.4, 3.2, 4.1, 4.3, 4.4 and 4.6. However, by the second research question (2), we assert that at the end of the course, students of years 2011 and 2012 were able to obtain the same level of basic competences expect competence 2.2 "Experimentación y descubrimiento de conocimiento" (Experimentation and knowledge discovery). Thus, we can conclude that the course strategy should continue improving in order to achieve greater robustness and validity of the developed teaching strategy.

To conclude with the presentation of results, we show the statistics of the projects developed in the course. These projects are grouped in three categories according to the origin of the idea: needs care, business opportunities and problem solving (See Picture 1).

In Figure 1, we appreciate the data of two years of course implementation characterized for having a balanced distribution of projects in two contexts: business-companies and social-external, where students made efforts to conceive, design, implement and operate their projects involving different private, governmental, social and rural entities, and resources of the University.

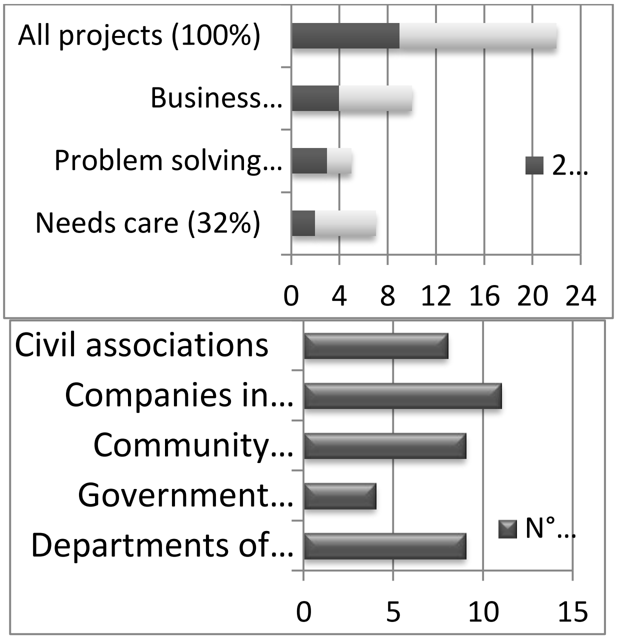


Fig 1. Project Statistics

Among the main projects developed in the social and external context are the designs of a solar dryer for organic coffee, improvement of hand-crafting cheese made from goat's milk, designing a collection center for coffee production and optimization of traditional process for eggfruit production, among others.

Among the projects developed in the context of businesses and companies are the design and experimentation for industrializing the traditional product from the north of Peru: corn chicha, for the production and extraction of ethanol from agricultural waste of banana, for the production of conglomerates from reusable containers, for the production of liquor from discarded banana, and for the making of anti-UV clothing, among others.

## 6. Conclusions

For the design of competences assessment for the Project Management course, were used the objectives of first and second level of the CDIO syllabus. Up to now, we have commenced work to ensure training and basic skills assessment according to these objectives of CDIO. The next step will be to rethink and/or adapt the subject of the course to reflect CDIO standards with the objective of improving actual content of learning and learning outcomes. Later, we could think about adapting proposed changes by CDIO at the faculty level.

The implementation of the syllabus and CDIO standards could be seen by the scientific and educational community as a difficult and tedious process, but the results obtained in the projects course –designed by following the guidelines presented in first and second level of CDIO syllabus- shows that are worth investing efforts for the implementation of it.

Among the benefits highlighted from experience, we found that it allows adjusting learning objectives to strategies and teaching methods. The objectives of first and second level of CDIO syllabus allow a more in-depth, clear and specific assessment of learning activities, which is the basis for the development and improvement of basic competences of the modern engineer.

Through the course of projects, it is intended to describe the features of teaching strategy that has allowed to improve basic competences in engineering students, such as: 1.1 underlying science knowledge, 1.3 knowledge in fundamental and advanced engineering, 2.1 engineering reasoning and problem solving, 2.3 systemic thinking, as well as 4.3 conceive, 4.4 design, 4.5 implement, and 4.6 operate projects in companies and in the social context. Nevertheless, teaching strategy based primarily on project learning should not be limited to this type of course in Engineering. Teaching strategy is a compendium of active methodologies that is complemented by doing workshops that allow you to route student's skills, mainly reinforced with the teacher mentoring role.

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