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Changing an Engineering Curriculum through a Co-Construction Process: A Case Study*

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The objective of this work is to present a co-construction process of an Engineering curriculum, which used different active learning approaches to motivate students by addressing realistic problems faced by engineers, right from the beginning of the program. Idealized by the rectory of the institution, in a top-down decision, the new curriculum established certain guidelines for these new approaches. In a bottom-up contribution to the curriculum, teachers had to devise, implement and conduct activities. At an early stage, these activities were classified into three types: Projects, Engineering Practices, and Workshops. To analyze the implementation of this new curriculum, a qualitative approach was used during and data were collected through interviews, focus groups, and questionnaires. The results indicate that teachers who devised the activities played an important role in determining several aspects aimed at formalizing the new curriculum in a co-construction process, increasing the accuracy of the ideas presented in the idealization phase. Despite the benefits of these experiences, the results suggest that the potential of the new curriculum was not entirely fulfilled at this initial phase, particularly regarding the development of soft skills. Therefore, adjustments are needed to take full advantage of the changes.

Keywords: curricular change; project-based learning; engineering education; active learning; curriculum co-construction

1. Introduction

Active approaches to promote the learning [1] can be introduced in engineering curricula in different configurations [2–4]. In some cases, they arise from individual teacher efforts or, in others, they arise from a small group of teachers who introduce strategies such as Peer Instruction [5], Flipped Classroom [6] or even Team Based Learning [7]. There are also schools that make an institutional decision to implement active strategies throughout the program, such as the experiences reported by Frenay et al. [2], Oliveira [3], Fernandes et al. [8], and Lima et al. [9], all of which involved curricular changes.

Powell and Weenk [10] argue that shifting to Project Based Learning (PBL) strategies is motivated by vision, consensus, or faith. Rarely this change is voluntary and may be motivated by government agencies or by the universities themselves. According to these authors, six factors influence higher education policies in engineering:

- Employers: by establishing market directives.
- Professional bodies: group of professional engineers and academics who, in associations, influence the training of engineers, such as the ABET (Accreditation Board for Engineering and Technology).
- International influences: posed by the market or by the engineering education community, serving as a beacon, inspiration and support for local decisions, as well as cooperating to introduce educational innovation initiatives.
- Students: can be seen as "the eyes of consumers", who give feedback on the teaching and learning process, and act as sensors of the labor market.
- Universities: in the case of engineering, bringing influences of external and internal validation in the country, through connections with other schools, their deans, and professionals.
- Governments: which, in addition to influencing the previous items through government policies, are responsible for enabling, organizing, evaluating and/or certifying the infrastructure supporting engineering programs.

In Brazil, engineering programs follow the National Curricular Guidelines [11, 12] which orient undergraduate engineering programs, with flexibility to address different contexts. They allow for continuous improvement and the introduction of innovation, such as new technologies and strategies. These guidelines indicate that engineering training aims to provide the future professional with the following general competences [12]: I. Formulating and designing desirable engineering solutions, analyzing and understanding the users of these solutions and

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their contexts. II. Analyzing and understanding physical and chemical phenomena through symbolic, physical, and other models, verified and validated by experimentation. III. Conceiving, designing and analyzing systems, products (goods and services), components or processes. IV. Implementing, supervising and controlling engineering solutions. V. Effective written, oral and graphic communication. VI. Working with and leading multidisciplinary teams. VII. Being aware of and ethically complying with legislation and the normative acts when exercising the profession. VIII. Being capable of learning and dealing with complex situations and contexts in an autonomous manner, keeping abreast of advances in science, technology and the challenges of innovation.

Considering the openness stated in the National Curricular Guidelines for engineering programs, the Mauá Institute of Technology, a Brazilian school, initiated a process of curricular change aiming to promote the development of transversal competences, preparing students to meet the needs of the market, beginning in the initial undergraduate program courses. The new curriculum foresees the replacement of traditional classroom hours by projects and workshops, aiming to develop both technical and transversal competences, increasing the students' ability to approach engineering problems. Another motivation to the curricular change was the visit by the pro-rector to an US university, with similar characteristics, where the extra-curricular activities carried out by the students had great importance in their curriculum.

Previously, the school had a traditional structure, comprised mainly of lectures followed by exercises and laboratory work. The principle was that students would feel more motivated to learn if, from the beginning of the program, they were given the opportunity of being involved in projects, workshops, and working in engineering laboratories. In addition to enhancing motivation, the adoption of various pedagogical approaches would promote the development of transversal competences aligned with the professional needs. These are beliefs, or faith, as stated by Powell and Wink [10], that started the change.

The introduction of active learning approaches is not an easy task, and some difficulties may arise, such as teacher resistance, the lack of adequate infrastructure, and/or of support of school management [13]. Faculty commitment is a key issue, because of their close interaction with students and because they face infrastructure challenges. Convincing them to work together to promote curricular change can be regarded as one of the main challenges in curriculum change. Curriculum change is not a linear process which begins with an idea and produces an immediate result. It is a process of co-construction, where teachers have part of the responsibility in the decisions, as well as other stakeholders [14, 15].

This article aims to analyze and evaluate the first year of implementation of a curricular change at a Brazilian engineering school. This curricular change aimed to put the students at the center of the learning process. The initiative was launched by the rectory of the school and was presented to the faculty, which started working to formalize and to put the new curriculum into operation. Implementation was not linear, and there were different interpretations of the process by the participants, issues which will be discussed in this study. The central elements of the curriculum, such as the different pedagogical approaches aimed at increasing student participation in the process, the roles of students and teachers, and the students' learning achievements are discussed. This evaluation considered the perspectives of the teachers, managers, and students involved in the change implementation process, during one and a half academic year, since the beginning of the implementation.

2. Research background

Curriculum development involves three stages: preparation, implementation and evaluation. It is a collective process, which includes people and procedures and involves interpersonal, political and social dimensions, in addition to the collaboration and cooperation of those involved. It is neither a rational scientific process, due to the subjectivity involved, nor a linear or systematized process. The subjective guidelines and its flexible features give curricular design a degree of openness, different from the design of a mechanism or a prototype [16].

From the conception up to its complete implementation, the curriculum undergoes different levels. Goodlad [17] indicates the starting point of a curriculum is an "ideal curriculum". After this initial step, there is the "formal curriculum", which is revealed in the curriculum documents, such as manuals and textbooks, and translates into the official curriculum. The third step is the "operational curriculum", which is developed by a group or single individual, which translates the ideas and formalism defined in the previous step into daily practice. Lastly, there is the "perceived curriculum", which is experienced daily classroom activity. There is also the "evaluated curriculum", which includes student assessment, and of curricular plans, programs, guidelines, manuals and textbooks, teachers, school, and administration.

To address the difficulties in training new engineers, Problem and Project-Based Learning (PBL) strategies are alternatives to traditional approaches in engineering curricula [9], and may be used to meet requirements posed by professional contexts [18]. These requirements simultaneously integrate technical and transversal competences in order to solve engineering problems. The current requirements for the engineering profession requires engineers to increasingly demonstrate competences that go beyond the technical know-how of their profession [19]. Some of the transversal competences required are leadership, the ability to work in teams, communication skills, entrepreneurship [20–23]. These competences that are not learned from lectures, in which the teacher just lectures students on steps that must be taken to carry them out. A competence is developed through meaningful learning experiences [1], which allow the student to develop and mobilize them before actually putting it to the test in a professional environment [24, 25].

Project-Based Learning (PBL), among other active learning strategies, is one of the most studied and important strategies [26] used to promote learning in engineering schools, and has been studied for some time [27]. Since design is one of the most important characteristics of Engineering, PBL and its variants have been largely used in engineering curricula. In PBL, teams of students cooperate in an interdisciplinary context, developing competences required in the labor market [18]. Experience has shown that when these strategies are used in the classroom [9, 28], students are more involved and motivated to learn, assuring the development of the new competences [29]. The main principle of PBL is student engagement, the resolution of open problems in an interdisciplinary setting, and active interaction with the object of learning, generally in teams [28, 30]. A problem is the starting point of a project, and it is up to the students to engage in search for a solution. Sometimes there are predefined milestones in which students need to carry out tasks and show learning improvement. In PBL, teachers also have to develop other communication skills and teaching strategies, shifting away from those of a traditional classroom. They need to assume other roles as tutors, mentors, and supervisors, helping students build their knowledge [31]. Kolmos [28] classifies different types of PBL: Assignment-based project—projects as part of a course; Subject Project—projects based on an entire course; Problem project—design by open problems—characterized by a problem and the development of a learning process that goes beyond disciplinary boundaries. Kolmos, De Graaff and Du [32] present a detailed analysis of PBL approaches involving seven dimensions: goals and knowledge; types of problem, projects and classes; progression, amplitude and duration; student learning; academic staff and facilities; physical space and organization; and student assessment and evaluation process.

The shift to PBL arise following some expectations [29, 33]: decrease dropout rates; to stimulate motivation for learning; to enhance the institutional profile; and to promote the development of new skills. The authors highlighted that the extent of this change sometimes took place in a single course or, in a more complex way, in several courses in an interdisciplinary context. Powell and Weenk [10] also listed three conditions for success when shifting to PBL: infrastructure, authority and consensus. The "infrastructure" dimension involves facilities, teacher training, and communication. The latter establishes a common basis regarding the perception of and the need for change. Authority is needed to promote adequate planning, guidance and progression to ensure implementation is accepted and institutionalized. Sharing of information and experiences, and the commitment and vision of teachers with a focus on student learning ascribe a bottom-up characteristic to the curricular project. Lastly, consensus facilitates the identification of crucial problems for the success of PBL, with the inclusion of stakeholders in the innovation process. "Cooperation between the teachers involved in PBL is just as essential as cooperation between students in their team" [10].

The faculty, school management, and limitations to school infrastructure shape the solution adopted for each curriculum proposal, constituting context and input, as discussed by Fernandes et al. [8]. Besterfield-Sacre et al [34], analyzing data from a wide survey with faculty, chairs, and deans regarding change in engineering education, noted that "many of the strategies and values of engineering faculty and administrators" converge into categories that favor change. These are:

- Curriculum and pedagogy, which inform individuals on new teaching concepts and practices encouraging their use.
- Policy to develop new environmental features that are required, or to encourage new teaching concepts and practices.
- Reflective teachers who encourage and support individuals in developing new teaching concepts and practices.
- Shared vision, which empowers and supports stakeholders to collectively develop environmental features that foster new teaching concepts and practices.

Also in this survey [34], teachers said they were aware of the learning opportunities provided by workshops and teaching and learning centers. They would be able to promote better use of new teaching skills to work with new curricular proposals and better promote student's learning.

3. Methodology

This is a longitudinal exploratory study with data collected before, during, and at the end of the implementation of a curricular change, using data from participants of this process: teachers, managers and students, to triangulate outcomes. The aim of this study was to analyze and evaluate the construction a curricular change during the first year of its implementation. Specifically, the objective was to understand the influence of proponents of curricular change and of proponents of different pedagogical approaches, managers and teachers respectively, regarding the change and their influence from the idealized curriculum up to the formalized curriculum.

The study of curricular change needs to be accompanied during a period that depends on the range to analyze. In this study, the option was to start at idealization up to the curricular operationalization, what represented 18 months. In addition, the choice for qualitative or quantitative data depends on the type of analysis to be performed. In this study, the option was for a case study using a qualitative approach, conducted during the first year of implementation of the curricular change, also using data collected before the implementation. Considering that the objective was to understand the way the curriculum was constructed, it became necessary to gather the views of the involved stakeholders, managers, teachers and students to better interpret their perceptions regarding this curricular change.

The research questions defined in the scope of this study were: What types of approach were proposed and carried out with students? What was the role of the proponents of specific activities in the development of the idealized curriculum? Regarding teachers' and students' roles in the process of learning, what changes took place between the idealized curriculum to the formalized curriculum? What was the contribution of the specific activities to students' learning? Was there a consensus among teachers, and among those teachers and the proponents of curricular changes, regarding specific points of the new proposal?

The data were collected through individual interviews, focus groups and questionnaires in four steps. The first step took place before the announcement of the curricular change, and aimed at determining teachers' perceptions regarding PBL. The second focused on the managers who proposed the curricular change, the aim being to know the motivation and expectation of the curricular change. The third step focused on the group of teachers who proposed the specific activities included in the curricular change in order to determine the aims of these activities, their relation with the elements of the curriculum, and their overall perception of the curricular change. Lastly, the fourth step focused on students and teachers to determine their perceptions regarding the implementation of the specific activities in the program. The specific activities included in the curricular change will be henceforth called PAEs (in Portuguese, "Projetos e Atividades Especiais"). More details on the PAEs will be given in the next section.

The data were collected over an 18-month period, from July to December of the following year, and are represented in this study as Month 1 (M1) to Month 18 (M18). M9 was the month the curricular change for students was implemented, and was also the beginning of the first semester of the academic year. The interviews were audio recorded with the consent of the interviewees and transcribed to allow accurate analysis of the information. The students answered the questionnaires in the school labs, totaling 694 and 626 in the first and second semester, respectively. All steps of the research are synthetized in the Table 1

4. Structure of the new curriculum

The Mauá Institute of Technology is a traditional engineering school in Brazil, which has offered traditional and teacher-centered approach courses for more than 55 years. At the time of this study, nine different engineering undergraduate programs were being offered. Students complete the program in five academic years. In the first two years, students take basic courses common to all programs, and in the final three they focus on engineering. Since its foundation, this may be the institution's most profound curricular change ever promoted, particularly by introducing PAEs in the curriculum.

The motivation for the curriculum change was to provide students with engineering content and practice right from the beginning of the program, with the use of the large number of laboratories available at the school. This complied with the National Curricular Guidelines [11], which calls for the promotion of learning in different contexts, beyond the classroom. The enhancement on project development was also a reason, so as to present students with engineering challenges from the beginning of program, as highlighted by an interviewee [Step 2] who stated that the change in mindset was the most important aspect of this experience, for replacing traditional classroom hours by other types of engineering learning activities. Visits to

Table 1. Steps of the research methodology

	Step 1	Step 2	Step 3	Step 4
Who?	Teachers of the school.	Dean and coordinator – Proponents of curricular change – who propose the ideas and implement the new curriculum, respectively.	Teachers who propose new pedagogical activities – PAEs.	Teachers and students during and after the 1st year of new curriculum.
When?	Before the new curriculum.	During curriculum idealization.	At the beginning of new curriculum implementation.	In the middle and the end of one year of new curriculum implementation.
	July (M1)	November (M5) and February (M8)	April (M10)	August (M14), November (M17), and December (M18).
How was it done?	Individual semi-structured interviews.	Individual semi-structured interviews.	Semi-structured focus group.	Teachers: Focus groups, individual interviews. Students: questionnaires.
How many participants?	7 teachers	2 managers	8 teacher proponents of PAEs in two focus groups – four participants in each.	12 teachers – interviewed 694 students – end of 1st sem. 626 students – end of 2nd sem.
What to know?	Perception and knowledge of teachers regarding PBL.	Motivation and point of view of proponents of curricular change.	Objectives, expectations, motivation and point of view of proponents of the PAEs.	Perception of students and teachers after each semester.
	What is PBL? Is it possible to use it in school programs?	Why change? How to change? Which improvements could the new approaches bring to the course? Is extra infrastructure needed?	What do PAEs bring new to the curriculum? What to expect from students and teachers?	What about the PAE implementation process: objectives, role of students, role of teachers, evaluation of learning: their contribution?

engineering schools by school board members of also helped to believe in the effectiveness of the initiative. All this supports the idealization of curricular change [17], and the development of guidelines for curricular change.

Initially, specific traditional classes were replaced by PAEs, which were designed by teachers who were free to make proposals involving a wide variety of subjects and pedagogical strategies. To better organize the curriculum, all PAEs were grouped in a course. When enrolling in this course, students select the specific Projects, Engineering Practices and Workshops they would like to take from a list of 38 options. Table 2 shows the previous and current curricular course load for the first academic year, with the inclusion of PAEs.

With the formalizing of the curriculum [17], the PAEs were classified into three different types: Projects, Engineering Practices and Workshops, according to different pedagogical approaches and periods. Table 3 shows the initial criteria used to classify the Projects, Engineering Practices and Workshops, and the period for each type of pedagogical approach. The proposing teacher was responsible for establishing the PAE period.

At the beginning of the first academic year, all students are required to sign up for PAEs. The weekly workload of any PAE is 2 hours, organized in a schedule that tried to match the interest of students and the availability of the teachers. During an academic year, students need to sign up for at least one Project, and a total of three Engineering Practices and Workshops: one or two Workshops, and complementary Engineering Practices. As a rule, the maximum number of students per group in a PAE is 30, but the proposing teacher could determine the exact number of participants.

All PAEs were designed according to the same general guidelines, established at the formalization

Table 2. Organization of hours in the previous and new curriculum, in the first academic year of each program

Curriculum	Physics	Chemistry	Calculus	Vector & Analytic Geometry	Algorithms and Programming	Technical Drawing	Introduction to Engineering	Total (classes + labs) / week	PAE Meetings/ week
Previous	4 C + 2 L	2 C + 2 L	6 C	4 C	2 L	2 L	4 L	28	0
New	4 C + 2 L	2 C + 2 L	4 C	2 C	2 L	2 L	2 L	22	6

C = Class hours; L = Laboratory hours.

Table 3. Initial criteria used to classify the PAEs

Pedagogical approach	**Initial classification**	**Period**
Projects	Directly related to engineering	one academic period – 8 months
Engineering Practices	Directly related to engineering	half academic period – 4 months
Workshops	Not directly related to engineering. To develop skills and knowledge, or to promote general background of other areas of knowledge	half academic period – 4 months

Table 4. Projects, Engineering Practices, and Workshops offered to students in the first year

Projects - Period of 8 months	**Engineering Practices – Period of 4 months**	**Workshops – Period of 4 months**
PRO 101 – Jam Manufacturing	PRO 701 – Fuel injection	PRO 401 – Mathematical bases
PRO 102 – Autonomous robot	PRO 702 – Spaghetti Bridge	PRO 402 – Graphics
PRO 103 – Flying over the campus	PRO 703 – Aerodynamics of buildings	PRO 403 – Competitive Brazil
PRO 104 – Water treatment	PRO 704 – Lean production	PRO 404 – Entering by cone
PRO 105 – Industrial shed	PRO 705 – Sustainable City	PRO 405 – The Logic of games
PRO 106 – Electronic games	PRO 706 – Chips Fruits	PRO 406 – Knowing LINUX
PRO 107 – Soap manufacturing	PRO 707 – "Houston, we have . . .	PRO 407 – The art of solving problems
PRO 108 – Weather station	PRO 708 – Mobile applications	PRO 409 – Modern physics
PRO 109 – Waterway	PRO 709 – Rocket Science	PRO 410 – Creating problems
PRO 110 – Skateboard factory	PRO 711 – Master user	PRO 411 – Negotiation
PRO 111 – Combustion engine	PRO 712 – Engineer Stirling	PRO 412 – Excel-VBA
	PRO 713 – Corrosion	PRO 413 – Python
	PRO 714 – Tensile/Compression	PRO 415 – Newton in equilibrium
	PRO 715 – Arduino	

level: activities should be carried out at the school with active participation of students; should not necessarily be associated with any course of the program; and no requirement of formal assessment of students' learning. On the one hand, these guidelines established certain rigidity; on the other, the opportunity and flexibility for teachers to freely design a variety of projects was an opportunity to encourage creativity. Approximately sixty teachers from different academic years and different areas submitted almost one hundred proposals for PAEs. Thirty-eight of these proposals were chosen to comprise the list of PAEs offered to students of the first academic year (Table 4), considering the following criteria: interest and feasibility for the engineering program.

5. Top-down and bottom-up co-construction of curricular changes

The curricular change was determined through an institutional top-down process, which guaranteed the authority required to support the process [10]. However, in the formalization and operationalization stages of the new curriculum, a great deal of freedom was allowed regarding pedagogical details, allowing teachers to provide input in a bottom-up contribution, as seen in Fig. 1. This section aims to show how teachers influenced this construction as agents of change.

The analysis of the data from the proponents of curricular change, the proponents of PAEs, and the students revealed four relevant dimensions used to discuss the implementation of the new curriculum. These dimensions were the construction of new curricular structure with the features of the three different pedagogical approaches; the role of the teachers; the role of students and; the contribution of PAEs to student learning.

5.1 Constructing the meaning of the PAEs

From the interviews with teachers who proposed the PAEs [Step 3], it was possible to attribute different meanings to the various pedagogical approaches. Projects, Engineering Practices and Workshops were thus defined:

Projects—Are divided into stages, and are related to an open and multidisciplinary problem, in accor-

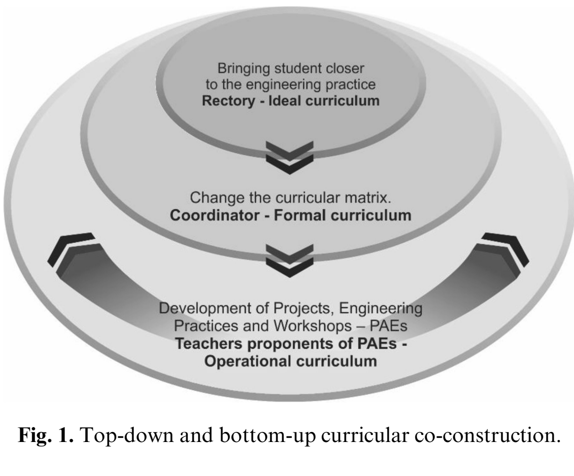

Fig. 1. Top-down and bottom-up curricular co-construction.

dance with Kolmos [28]. For these teachers, open problems are those that may be solved in a variety of ways, or that use a variety of tools in the solution. In the words of one interviewee.

> "*[Project] . . . is something bigger, in which I need more resources, different types of knowledge from specific engineering areas, in my case, automation control . . . I have to do research, I have to see how it works (the software, the mechanism) . . .*" [FG2P4—Focus Group 2, teacher 4].

For those interviewed, Projects required a working strategy, which required team organization, defining the roles of participants, identifying the problem, and defining the steps for the solution. Content needed to be presented by the teacher to support the work of the teams. Students needed to conduct research to support problem solving process, to search for a solution, to develop and test a prototype, and finally, to make an oral or written presentation of the results.

Engineering Practices—For some interviewees, Engineering Practices, unlike Projects, do not require initial research to define and find the solution to a problem. Teachers directly present both the content and the problem, and students work directly on a solution.

> "*The student will carry out a proposal that is already half set by the teacher. The specific objective is set by the teacher*" [FG2T1].
>
> "*. . . the student can give his or her solution, but it's very controlled, with the teacher controlling the process to reach a specific goal also set by the teacher*" [FG2T2].

There are also those who identify Engineering Practices as open mini-projects, only because they have a shorter development period, not requiring much initial research in technical articles [FG2T3].

It is possible to conclude that, in Engineering Practices, the goal is to develop engineering competences such as on laboratory work, focusing on implementing a process or building a product directly, with less autonomy to fully develop student creativity.

Workshops—The aim is essentially to have students develop competences in workshops structured in two stages: first, a theoretical presentation of specific content is given by the teacher, and in the second, the teacher proposes specific supervised work to the students. Generally, this begins and ends in a single class [Focus group 2, teachers 1, 2 and 4] and may have involve direct interaction, with the handling of parts, equipment or tools, or installing or building a prototype. It may also be used to promote the development of pencil and paper activities. An example is "Mathematics bases", which aims to develop mathematical skills which the students find difficulty.

> "*I think a workshop has content to be addressed, but without the need of creating a product as a project, but of gaining knowledge on certain content*" [FG1T2—Focus Group 1, teacher 2].

In summary, Engineering Practices are associated with the application of an engineering tool without the involvement of many variables nor the design of large complex projects. In this case, problems are not an open problem. In turn, Projects are associated with open and multidisciplinary problems whose solution is unknown, and are developed in stages. Workshops are associated with the development of specific technical, scientific or transversal competences, to support engineering background and to broaden knowledge.

At end of the academic year [step 4], it was possible to realize that some teachers still assigned different meanings to these pedagogical approaches. For example, Engineering Practices and Projects were perceived as having the same features. That is, after one academic year there was still no consensus regarding the features of these pedagogical approaches and different teachers assigned different objectives to the same type of pedagogical approach. According to Powell and Weenk [10], consensus is a basic condition to implement PBL and, the lack of a consensus regarding the role of each PAE certainly hinders uniform work.

For the students [Step 4], each pedagogical approach, or different type of PAE, followed different pedagogical strategies, which are shown in Table 5. In Workshops, meetings to solve exercises predominated, followed by lectures. In Engineering Practices, laboratory classes and projects were more frequent. In Projects, as expected, the students identified the predominance of projects, followed by Laboratories and Lectures. It is interesting to notice that meetings to solve exercises in Engineering Practices was not a significant option.

The predominance of two pedagogical

Table 5. Different pedagogical strategies used in the PAEs (%) from the student perspective

	Lectures	Resolution of exercises	Laboratories	Student seminars	Case studies	Games	Projects
Workshops	22	**36**	9	3	14	**2**	14
Engineering Practice	18	**5**	24	12	10	8	**23**
Projects	21	2	**24**	12	6	**1**	34

approaches for Engineering Practices, "Laboratories" and "Projects" confirmed the mixed views teachers also had regarding these types of PAEs. Student perceptions showed they would either be working on a project or conducting laboratory sessions. Analyzing teachers' perceptions [Step 4], it was possible to conclude that the small number of students in the groups, as determined by the teacher, favored the process of putting active learning strategies into practice, providing more individualized attention to the students. It is interesting to notice that Lectures appear in all approaches, indicating that teachers continue giving classes in a traditional manner.

In the idealization stage of the new curriculum, the desire to include practical projects in the curriculum was mentioned. The concept of Projects, Engineering Practices and Workshops appeared in the formalization phase, when these different pedagogical strategies were originally defined. Only in the operationalization stage were these approaches better defined by the proponent teachers, who played an important role in this characterization.

5.2 The Teachers' roles

A positive aspect regarding teachers in the curricular change was their acceptance of the challenge to develop PAEs and the willingness to learn [Teacher 4; Step 4]. "*Developing PAE was pretty cool. Teachers devote time because these are subjects that he likes*". This statement met the expectation of the proponents of the curricular change [Step 2], as its possible to realize from the statement "*the curricular reform aimed at broadening the teacher's exercise of his or her competences*". It shows a convergence between the school board's intention and the action of teachers who had the opportunity of putting their competences into practice.

In the previous stage of the curricular change, when discussing PBL [Step 1], teachers assigned themselves different roles that may be regarded as a facilitators of the learning process [35].

> "*. . . (teacher) tries to make students question themselves and search for solutions to the problem.*" [Teacher 1].
>
> "*. . . because of the greater proximity to the student who is responsible for learning.*" [Teacher 2].
>
> "*. . . to say the work did not end as soon as the student got the result in the calculator, and then ask 'what is this? Is it important? Why did you use that?' He must be orientated.*" [Teacher 3].

These teacher roles were confirmed and further detailed by proponents of the PAEs [Step 3]. They indicated a refinement of conceptions regarding the role of the teacher. According to them, teachers' roles were: advisor, tutor, model, content provider, and team coach [31], always promoting student autonomy. As the curriculum reform progressed, teachers became more aware of the new competences that needed to be set in motion when working with students.

Teachers' roles were defined differently according to each PAE pedagogical approach. In Projects, the teacher role was viewed predominantly as that of a team coach, helping students assume their roles, carry out the tasks, and engage in good interpersonal relationships. In Engineering Practices, the teacher was perceived predominantly as a role model, an example to be followed by students. In Workshops, they were regarded as tutors, as someone who supported efforts, respecting the different student profiles. In all these roles, there was the idea of developing autonomy in the student.

It was possible to determine two different dimensions associated with teacher roles. One was operational, related to carrying out PAEs, making them happen. Another was related to the pedagogical dimension, determined by the different demands of each PAE approach.

5.3 The students' roles

The reason to implement a new curriculum and the PAEs, as revealed by the proponents of curricular changes [Step 2], was to help students be better "*prepared to accept challenges*", be involved in the "*solution of open problems and projects*", and to "*practice engineering by working in teams*". In addition, PAEs were expected to bring students closer to laboratories and companies, right from the beginning of the first academic period of the engineering program. There was no specific indication as to which transversal competences were to be developed with the PAEs.

At the initial phase of implementation of the curriculum change, it was possible to gain a perspective of student roles, from the teachers' point of view [Step 3]. Students would be able to "*make choices*", "*take decisions*", "*solve problems*", "*conduct research*", "*carry out the practices proposed by the teacher*," and "*have a proactive attitude*". These are more specific contributions that PAEs may have towards enhancing student competences.

At the end of the academic year, the evaluation of student involvement, done by teachers [step 4], brought contrasting perceptions. Some teachers indicated a negative point of view, arguing that while the teacher accepted the challenge of creating something new, the students did not embrace the opportunity to face the challenge. For these teachers, students understood the work proposed more as a task to be fulfilled in order to earn the credits, instead of an opportunity to develop additional competences. As stated by an interviewee *the "PAE was very nice, but students showed little* *interest. Most of the students chose PAEs because of the schedule. Sometimes it seemed that some teams were totally lost.''* [Teacher 10, step 4].

In contrast, there were certain positive indications of the involvement of autonomous and motivated students. ''*In the laboratory tasks, the students stayed longer, even after established working hours, without complaints.*'' [Teacher 8, step 4]. According to Teacher 11 [Step 4], the students at times ''*were excited, surprised, and impressed with their achievement, their own abilities. They worked at their own pace*''.

Developing new competences and broadening experiences to bring students closer to actual engineering practices were envisioned during curriculum idealization, but it was not clear how this could be performed in the curriculum formalization stage.

Proponents of curriculum change focused on the structural curriculum changes: the focus was to ''*set the program in motion*''. In turn, teachers who proposed PAEs were those who defined the competences students needed to develop in a more precise manner. Interviews [Step 3] indicated that PAEs could help students develop transversal competences.

The development of transversal competences was perceived as the main contribution of the PAEs. However, the organizational issues of putting the new curriculum into practice seemed more important, impairing all its learning potential during implementation.

5.4 Results—contribution of projects, engineering practices, and workshops

The proponents of the new curriculum [Step 2] expected the PAEs to make the students more active, committed, dedicated and effective team players. For the teachers proposing the PAEs [Step 3], the greatest merit was to highlight engineering function during the learning process, to use course content in problem-solving activities, and to encourage students to assume responsibility for their own learning in a context freedom.

At the end of the academic year [Step 4], teachers perceived student participation in PAEs differently. As pointed out by teachers ''*the cultural gain went beyond engineering, for example astronomy*'' [Teacher 4, step 4]. Regarding the development of competences, teacher 8 referred to certain gains in teamwork and critical judgement: ''*teamwork, the attitudes in the presentation of results, and the ability to compare results between teams. They also noticed limited Internet information due to low technical content*'' [Teacher 8, step 4].

Some teachers stated that the PAEs should have had a stronger and more explicit connection with the program's courses, addressing content such as physics, mathematics, and others, reinforcing their importance [Teacher 6, step 4]. ''*The gap between PAEs and the courses ended up generating more difficulty, contrary to what an interdisciplinary project was expected to provide. PAEs and the program courses ended up being two separate things*'' [Teacher

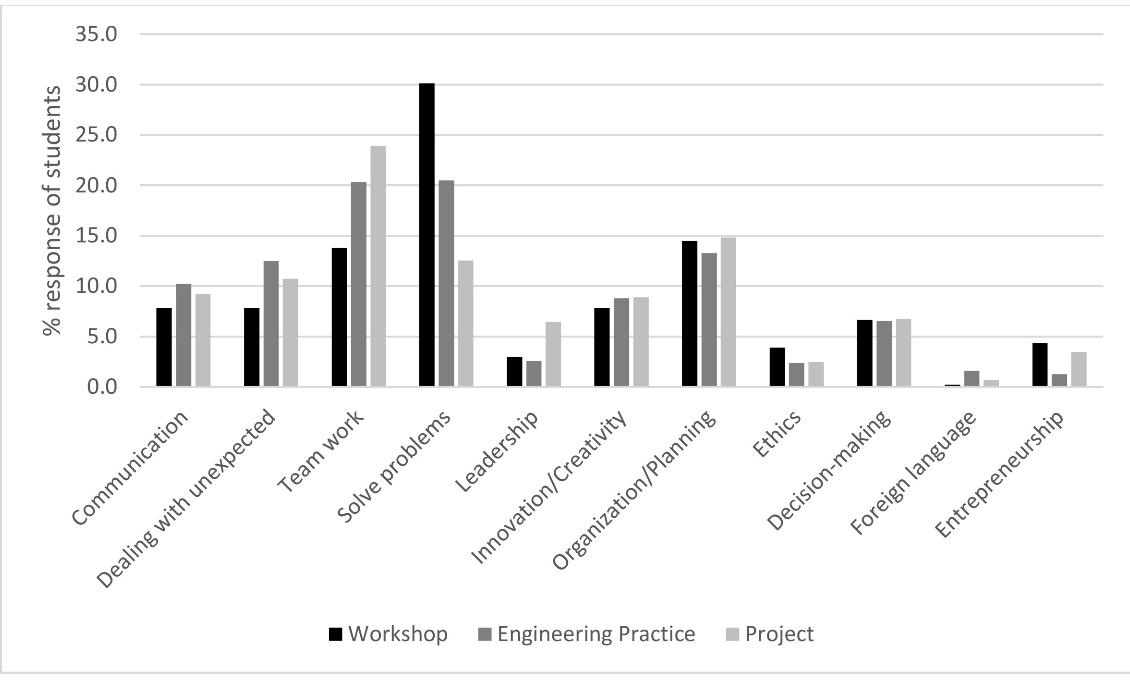

Fig. 2. Transversal competences developed in the PAEs (%), from the student perspective. *Note*: Students could choose more than one option.

7, step 4]. The analysis of teacher interviews showed a marked contribution of the PAEs towards the development of transversal competences, but this lacked a connection with the courses of the program.

Results demonstrated that PAE objectives diverged. While the proponents of curricular changes requested transversal competences, some teachers [Step 4] showed the need to link PAEs with the courses of the program.

Students shared the same point of view, pointing out that course content should be a strong point of the PAEs. "*Knowing, practicing, and having contact with*" engineering knowledge was the aspect most valued by the students. They attributed less importance to learning transversal competences. In addition, they pointed out that participation in PAEs took time and represented additional student work [Step 4].

Despite these statements, students highlighted certain transversal competences developed in the PAEs, especially in the Projects: "*Teamwork*", "*Organization and planning*", "*Problem solving ability*", "*Ability to innovate*" and "*Ability to deal with the unexpected*". Figure 2 shows, from the view of the students, the transversal competences developed in the PAEs.

In general, the students were able to fulfill PAE requirements and obtain a passing grade but, overall, teachers felt that there was not enough perception of the importance of PAEs in their training.

The analysis of the results shows the need to improve the connection between PAEs and the courses that run in parallel. This connection could increase the sense of meaning for both, the courses and the PAEs, thus increasing motivation and engagement of the students.

6. Conclusions

The top-down decision by the school board provided the authority to ensure the implementation of the new curriculum. A bottom-up contribution by the proponents of the PAEs, defining their structure and detailing the role of teachers and students, guaranteed the co-construction of the curriculum. The top-down initiative supported the changes and promoted the involvement of teachers, and the bottom-up initiative developed the curriculum.

As the curricular change was outlined in a non-directive way, it was possible to open space to the contributions and influence of teachers in the curriculum formalizing phase. The three types of approach, Projects, Engineering Practices and Workshops, initially defined in an open way, were over time defined in a more specific way by teachers, reflecting the commitment to the challenge, allowing to leave their mark in construction of the curriculum, as was envisioned in the curricular formalization stage. Although the full transversal competence development potential, was not fully realized in this first year, teachers became aware of the role they should play in guiding and supporting students' work to achieve these skills. The transmission of content was perceived as more important than the development of competences, but the importance of soft skills was recognized by teachers in the training of students.

From the teachers' point of view, the students did not have the desired level of awareness of the importance of the new approaches in their training, and regarded the PAEs as tasks to be fulfilled in order to obtain a passing grade, instead of being perceived as learning spaces for the development of competences. Both teachers and students stated that the PAEs should be more closely connected to course content. This indicates that the idealized curriculum has not yet developed an identity with regard to operationalization.

Better communication with the students regarding the objectives of the PAEs, clarifying their contribution to the development of competences, is required. In addition to the authority, infrastructure and consensus needed to promote change among teachers, effective communication is also necessary to increase awareness and to ensure the involvement of students in a new curriculum that values competences.

This study revealed that curriculum change is a co-constructed process, requiring the alignment and contribution of all stakeholders involved: leaders, teachers, and students. This co-construction of the engineering curriculum is an ongoing process aimed at continuous innovation.

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