Engineering of Self:
Twenty-Five Years of Experience Developing New Skills and Expanding Boundaries for Chilean Engineers[1]

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"Few institutions are so conservative
as the universities about their own affairs
while their members are so liberal about the affair of others"
- Clark Kerr[1]

Introduction

Accelerating the rate of change in engineering education is an urgent need that today nobody questions[2], but achieving change is not at all an easy task[3]. Introducing changes is particularly difficult in conservative organizations as is the case with universities[4].

Introducing new objectives, disciplines, and methodologies in an engineering program challenges the curriculum, teaching skills, infrastructure, and power structures, among others. Some areas have to yield credits, resources - and power! This task is much harder when new elements represent ideas that go beyond and challenge established paradigms[5].

Historically, many of the new initiatives are resisted and not adopted. Others overcome resistance and are adopted only to be reversed later[6]. Only a fraction of them advance and become part of the curriculum. Here, we present an experience we believe belongs to the last category, an innovative initiative started in 1986 in the Industrial Engineering Program (IEP) at the University of Chile that is still alive and slowly expanding into other areas of the School of Engineering and Science (SES).

Twenty-five years ago, biology of cognition and radical constructivist theory were introduced as epistemological components of the theoretical debate about pedagogical improvements among a faculty group in the Department of Industrial Engineering (DII), the academic unit in charge of the IEP. Since then "Learning to Learn" has been included as a central learning objective in the IEP introductory course.

In the 1990´s, learning and entrepreneurship learning objectives were combined to give rise to the "Learning to Start Starting by Learning" concept and pedagogical orientation at the undergraduate level. Going beyond traditional technical capacities was thus believed to produce not only new professional competences in the medium term –after graduation- but also new

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learning competences in the short term. In 1999, all this effort lead to the creation of the "Programa de Habilidades Directivas (PHD)" (Management Skills Program) as an attempt to include in all the educational levels in the DIE - undergraduate, graduate, and continuous- a wide variety of social, management, and leadership skills required by engineers to deal with what Peter Drucker called "New Realities" of the twenty-first century[7].

This paper is a reflexive retrospective of these twenty-five years of introducing new perspectives, paradigms, disciplines, objectives, methodologies, practices, and courses with a radical constructivist orientation in the DIE. We present a working hypothesis aimed at understanding why this innovation program was successful. Thus, we reconstruct the evolution of the PHD and reflect on its successes and failures, its turning and tipping points, and its weaknesses and strengths. An immediate, clear, and robust conclusion was that not having established systematic assessment methods from the PHD's beginning was a serious mistake. This is one of the areas in which this paper aims to simultaneously help and benefit from others involved in similar efforts of innovation in engineering education.

The paper presents a historical and contextual background to understand the PHD's genesis. Then, it describes the theoretical framework and its instructional model. It also explains three different approaches used to evaluate this historical reconstruction, followed by the main results. Finally, it discusses some suggestions learned from experience, especially from the mistakes, about how to sustain changes that expand the boundaries of engineering education, inviting to formulate ideas on how to evaluate and assess these ambitious initiatives in the long-term.

Cultural, Social, and Historical Context

Culture matters[8], and history and social contexts matter too[9]. Engineering education is not an exception[10]. Its evolution is related to historical, social, and cultural contexts[11]. In this section we give an overview of the context in which this twenty-five years program was designed and implemented.

Unlike other countries, since the nineteenth century engineering has been one of the most prestigious professions in Chile. Moreover, in recent decades its relevance has increased further. Engineering programs attract and enroll the best students from the secondary school system, and engineers' salaries rank at the top of salary scales. It is not rare to see engineers as captains of industry, leading public institutions, and in high political positions.

Founded in 1842, the School of Engineering and Science (SES) at the Universidad de Chile was the first school of engineering in Chile, and has always been one of the leading research institutions of the country, receiving the largest proportion of public R&D funds in comparison with other academic units. The SES has about 200 full-time faculty members and

approximately 4,000 students. According to the national university entrance test (PSU), each year the SES receives freshmen from the top two percent of high school graduates.

All SES's freshmen are enrolled in a "common core" program that last two years and a half. Then they choose among nine engineering or four science programs. Most students (more than 30 percent) nowadays choose the Industrial Engineering Program (IEP), created in the 1950s.

This program, which has been paradigmatic and influential for most universities in Chile and some others in Latin America, was the result of a first, pioneering, and relevant educational innovation: the introduction of economics and management as a central and distinctive component of the IEP's curriculum.

In the 1960´s, the IEP benefited from the emergence of the Department of Humanistic Studies at the SES. At this center, at that time the best in its area, industrial engineering students added a humanistic, social, and artistic pedagogical affluent to their training as professionals and human beings.

Another important feature to be considered in the interpretation of the growing success of SES engineers, especially industrial engineers, is the crucial value that autonomy and independent thinking has played in the development of the academic and student community. Historically, the capacity of critical thinking and a dialectical and constructive relation with the surrounding environment, both public and private, has been a very proudly defended characteristic of the SES. As a matter of fact, this allowed the SES to be one of the very few places where Pinochet's regime could not rule during the 1973 to 1990 dictatorial period. This fact is one of the reasons why some people refer to this academic community as "The Independent Republic of Beauchef" (Beauchef is the name of the street in which the SES is placed).

In 1986, an innovation process started in this cultural, historical, social, and emotional context. The first named author of this paper and the famous Chilean biologist, Professor Humberto Maturana (National Science Prize in 1994) initiated a dialogue and began to collaborate professionally. The interaction led to a first milestone in the design and implementation of the Biology of Cognition course that has been offered as an elective course to undergraduate students since 1987. It is important to note that a group of full-time faculty fully or partially attended the first version of this course. They were the ones that ten years later succeeded in introducing the constructivist approach to education as part of the compulsory program of the IEP.

Also in 1986, Fernando Flores, former Minister of Finance during the government of Salvador Allende, and at the time living in exile in California, was creating radical innovative theories about underdevelopment and management. Conversations with him led to the introduction of entrepreneurship and ontology of language as two new elements in the IEP curriculum.

The next two sections describe the theory and instructional framework developed along these lines in the twenty-five years that followed those foundational moments.

Theoretical Framework

A central element of the biologically based radical constructivism proposed by Maturana and Varela[12 13] is that human beings are structurally determined, which implies that anything that happens to them (us) is not determined by external perturbations but only triggered by them. This assumption means that human beings can never know how things really are: they can only know how they live them. Reality is not independent of the observer but created by the observer in the process of observing. Each person creates different realities depending on their paradigms, moods, and interests, which are unique and socially and historically determined.

This epistemological assumption, which is the basic element of any constructivism, is accompanied in the radical versions of constructivism by an ontological assumption: human beings are also a construction of human beings. We can never know who and how we really are. We can only know how we observe ourselves. And we observe – and thus construct ourselves- according to the paradigms, moods, and interest through which we observe ourselves.

These two assumptions have radical implications for education. Not only there is no teaching but only learning, which is the most well know constructivist proposal. Besides, there is no immanent and permanent self that learns. The self is also the result of the process of learning. Students construct simultaneously and interdependently the external reality and the self. We human beings engineer reality and ourselves in a continuous and never ending process.

If we adopt these premises, then students have to be allowed, empowered, and helped by their instructors in the task of continuously designing, leading, managing, assessing, and redesigning their process of inventing reality and inventing themselves at the same time.

Instructors become designers and facilitators of contexts aimed at allowing students to do this in an efficient and autonomous way. But instructors are also human beings that create reality and themselves depending on their own paradigms, moods, interests, and the context in which they live[14]. Thus, in this model, all actors involved in education are subject to an evolutionary and transformational process. The key factor of this learning and transformation process is the level of awareness and self-control of each actor involved in it.

This radical constructivist approach has several benefits. First, it lowers the pressure on instructors to spend more of their scarce and costly time in improving their teaching abilities, which is – especially in traditional research universities- an almost impossible task for some of them. Second, it helps in the process of improving the design of educational experiences[15]. Third, it makes students more responsible for the design and management of their learning program,

allowing the development of entrepreneurial and innovative capacities as a parallel and related pedagogical goal.

Later, in the 1990s, influential management thinkers strongly emphasized managers' self-awareness. Peter Drucker argues that the most crucial management now is managing oneself[16]. In December 2001, the Harvard Business Review broke new ground by publishing a special issue entitled "Breakthrough Leadership: Why the Best Strategy Today is Knowing Yourself."[17] It is important to realize that this was the first special issue of this prestigious and influential journal in its 79 years of existence. The special issue did not focus on marketing, finance, strategy, sales, production, operations management, technology, quality service, or other main management topic. Rather, it drew attention to the human side of management. The following sentence, extracted from the editor's letter is particularly revealing of this crucial shift in management:

> "The term "breakthrough leadership", as we define it, is multivalent – it points in several directions at once. Certainly, it involves breaking through old habits of thinking to uncover fresh solutions to perennial problems. It also means breaking through the interpersonal barriers that we all erect against genuine human contact."

Through time, this view has matured, consolidating the focus on increasing self-awareness. When these ideas are developed within an engineering environment, the idea of an engineering of self begins to take hold. Assuming the radical constructivist approach consistently and to its final consequences – what we call the radical-radical constructivist approach- implies assuming the inescapable role of individuals as engineers of their lives. This approach led to the launching of the course "Design and Management of Self" as an elective in 2000.

These theories, mentioned above, are structured in a basic instructional model of four phases:

1. *Cognitive phase or knowing the content*. Participants are invited to learn about the philosophical, psychological, sociological, and management developments on which the PHD is based. This first phase is particularly important in an engineering educational context because students usually have been trained and perform well in a cognitive sphere. Therefore, they know how to argue and defend themselves from the risks of manipulation and dependency that appears when the emotional and spiritual components of individual formation emerge.

2. *Attitudes and skills.* Having achieved a good understanding of the cognitive side of the constructivist proposal, students are invited to immerse in a set of exercises and

recurrent practices with the goal of experiencing the attitudes, skills, and emotional side of living and learning.

3. *Increasing self-awareness.* The main goals of the exercises and practices are not so much for students to improve in these dimensions – which is not an easy task in short periods of time- but to improve as observers of themselves and increase consciousness of the level of competencies at which they are, and the consequences in terms of their performance as students, citizens, and future professionals.

4. *Redesign.* In the last phase of the learning chain, students are invited to go back to the cognitive sphere, in which they are usually highly competent, to redesign the way in which they are designing and managing their learning process and their behavior in general.

The use of this model during these twenty-five years has strengthened the PHD in two dimensions: the role of emotions in educational context, and the relevance of a continuous evaluation. According to a radical constructivist perspective, emotions modulate the way in which we perceive and construct reality. Because emotions are present in each step of a learning process, a battery of instruments and practices were developed to increase the capacity to indentify, acknowledge, accept, and modify emotions. Some of these instruments and practices are presented in the next section. Regarding continuous evaluation, each step of the model requires a highly developed ability to constantly self-asses and self-evaluate personal progress. Here, the participation of classmates, instructors, and other external observers is fundamental.

Instructional Activities

After the first courses, the PHD was growing inorganically (or in an unstructured way), and different strategies and dimensions were tested and implemented. Thus, the program expanded its actions to undergraduates, graduates, and continuing education, and certain workshops and short-programs for adolescents and community leaders. Courses, workshops, and conferences were constantly offered. In this section, we describe the main components of these activities, starting from the more specific elements.

Basic practices

As stated above, although to expose students to a cognitive understanding of the courses' content and theoretical proposals was part of the learning objectives from the outset, the central focus always was on the acquisition of certain emotional and corporal attitudes and skills. Thus, practical and hands-on activities rather than cognitive or passive activities were the program's cornerstone. The following four exercises were the most frequently used and relevant activities of the program:

- *"Tuning in."* Exercise used at the beginning of any course or workshop session. Its main objective is to set the participants' mood and emotion. Through this exercise, participants are trained to identify their moods and emotions and realize its influence on the reality that they "construct" at each moment. In addition, an improvement in student focus on the session is expected. Specifically, through the "Tuning in" each participant is invited to indicate their moods, emotions, interests, questions, and worries upon arrival. This exercise consists of a one-page questionnaire that includes a list of twenty-seven moods of which each participant has to select three that best represent their moods and emotions upon arrival. This list includes positive and negative moods and emotions.

- *"Stretching."* Exercise used at the end of every course or workshop session. Its main objective is to improve participants' capacity to assess their learning and increase awareness of themselves as active participants in the course. This exercise is also a one-page questionnaire that includes the same moods and emotions list of the "tuning in."

- *"What I learn" essay*. Weekly practice in which students must write a one-page essay about their insights, learning and specific changes observed during the week.

- *"Ship's log book."* Following Drucker's proposal on the importance of feedback, students are invited to initiate the use of daily notes on a sort of "Diary of Learning and Living", registering emotions and moods, insights, questions, concerns, breakdowns, etc. Although this activity is not reviewed nor graded, an important percentage of students adopt and value this practice.

The exercises described above are focused on self-observation and evaluation. In recent years, new exercises that include evaluations and observations from the students' networks have been included. For example, the students' families and friends are asked to complete a questionnaire about students' practices and behaviors.

Courses

The PHD has offered many courses for undergraduate students during these twenty-five years. Here, we describe five courses. Although only one course was mandatory, and the other four were electives, the elective courses have had full enrollment almost every semester.

- *Biology of Cognition*. The first version of this course was offered in 1986 by Humberto Maturana and was considered the PHD's genesis. Since then, the

course has been offered continuously each fall semester. This is a content-driven course that presents the basic theories and principles of the Biology of Cognition. Usually, advanced students that want to obtain a deeper understanding of the PHD's foundational knowledge take this course.

- *Introduction to Industrial Engineering.* This course was the most important course directed by the PHD and the first compulsory course for those students that, after the engineering "common core", choose the IEP. The course's main objective was to induce and allow students to become designers and manager of their personal learning program while they discover the industrial engineering world. Thus, the course promoted an active student attitude toward their own undergraduate studies. The first version was offered in 1997 and the last one in 2008. After 2008, the objectives of this course were split into three courses called Industrial Engineering Workshops I, II, and III. These new courses maintain the main orientation of the Introduction to Industrial Engineering course and are framed within an important curricular reform at the University of Chile that places students at the center of the learning process.

- *Entrepreneur Skills Development.* Elective course opened to students in the last two (of six) years of the IEP. The main objective is to immerse students in a real experience of designing and attempting a start-up project. In this course, the main focus is also on the student learning process rather than on the content or on the student project itself. This course was offered for the first time in 1991.

- *Management Skills Development*. This elective course is designed to promote students' management skills, such as organizing, delegating, communicating, leading, team building, and time-management. This course is almost completely based on active learning. Each session involves exercises and practice; lectures and content are almost absent. An important feature of the course is that, during the first part, students have to identify those management skills in which they are strong and those in which they are weak. Each student has the opportunity to explore and improve a particular skill. This course was offered for the first time in 1998.

- *Design and Management of Self*. This course is aimed at reflecting on the different aspect of the professional and personal life, to increase self-awareness, and to explore the possibilities, costs, and limitations of the design and management of self. Humberto Maturana and the first named author of this paper offered this course for the first time in 2000.

Saturday Workshops

A large series of workshops has been designed and offered by this program. Most of these workshops were daylong Saturday sessions to ensure participants' emotional involvement. These workshops were usually aimed at introducing students into the radical constructivist approach through a sequence of individual and group activities. A well-known version of these workshops was the "Business Game." This game, which simulates the real business world, was used to trigger students' insights and conversations about self-awareness and management skills.

Graduate and Continuing Education

The PHD has had a large impact on the graduate and continuous education programs, and has enjoyed fast growth. The PHD became one of the most distinctive components of the University of Chile's MBA and offered many post-graduate diplomas and programs for different Chilean companies and regions, enrolling many political, business, and community leaders[18]. Although graduate and continuing education is not the paper's focus, we acknowledge a strong influence from this experience on undergraduate education, and vice versa. This influence and the overall impact of the PHD on graduate and continuing education need further research.

Methods

Because this paper reconstructs the PHD history and reflects on it, we analyzed historical documents (i.e., first versions of course syllabi) and data, and also we summarized a series of papers that have described and evaluated various aspects of the program. We must point out that the paper's first named author was one of the leaders and founders of the program and the co-author was a student and later became instructor in the program. This familiarity with the PHD has the advantage of providing first-hand access to the program's history and evolution, but it also has the limitation of not ensuring an objective and neutral evaluation and assessment of the impact of the program.

We classify the methods into three different strategies: an analysis of the curriculum evolution, the collection of cases of students' projects influenced by the PHD, and surveys answered by current and former students. First, we collected old versions of the PHD's course syllabi and analyzed the evolution of the credits offered by the PHD in the IEP. We also speculate regarding some aspects of the PHD influence on the SES's curricular reform. Secondly, we collected from past course evaluations and reports some successful initiatives, projects, and programs created and led by students influenced by the PHD. Finally, we summarize a series of papers that analyze and evaluate quantitatively and qualitatively different aspect of the PHD's courses. These papers systematized data only since 2000. Unfortunately we do not have systematized data for the period ranging from 1986 to 2000.

Results

According to the three strategies explained in the methods section, we grouped the results into three categories: influences on the curriculum, success cases, and survey and data systematization.

Influences on the curriculum

A way to measure how a new initiative grows in an undergraduate program is looking at the amount of credits offered to the students. Figure 1 presents the total amount of course credits offered by the PHD per academic year since its beginnings in 1986. In the SES, one credit means one hour (60 minutes) of study per week. For example, in the SES a normal mandatory course has 10 credits, which means that students have to allocate 10 hours per week to the course, including lectures, labs, personals study, and any related activity. A normal student is expected to achieve 100 credits per year. In 1986, the six-credit course Biology of Cognition was offered in fall and spring, adding 12 credits for that year. Then, this course was offered only in the fall semester. Since 1990, other courses were included in the curriculum. The peak of the PHD was in 2001 when 68 credits were offered through one mandatory course and four electives. The number of credits represents the relevance that the PHD had at the time in the IEP's curriculum. In total, twelve professors have been trained and have taught in the PHD. Half of them were engineers, and four have received the award as best IEP's professors.

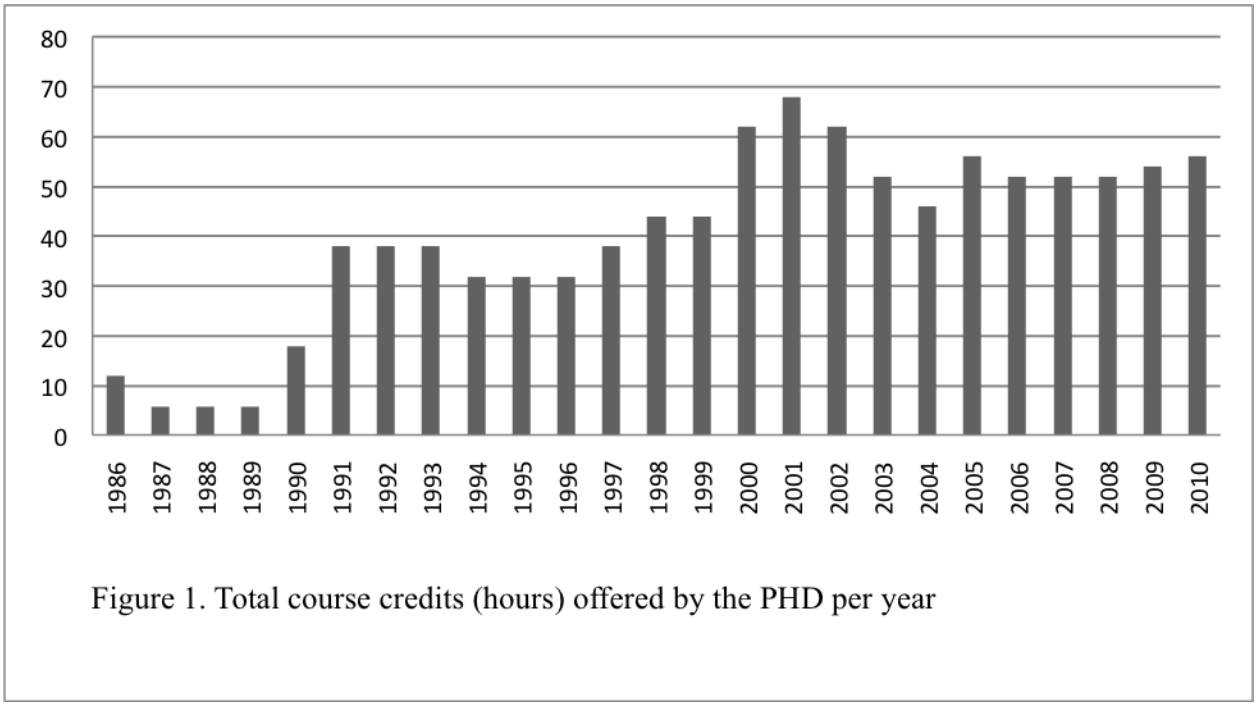

Figure 1. Total course credits (hours) offered by the PHD per year

The PHD also contributed to the undergraduate education through other courses that are not included in Figure 1. Some "Thesis Project" sections, the last course in the IEP sequence, and some "Design Project Seminar" sections, a course offered to engineering sophomores, have been conducted by PHD instructors.

In 2002, the School of Engineering (SES) started a discussion process on its curricula that concluded in a large curricular reform implemented in 2007. This reform puts the students at the center of the learning process and incorporates active learning methodologies and other innovations from the engineering education's state of the art[19]. The PHD was aligned with the reform's learning objectives, and made a contribution to the discussion process in two important ways. In 2005, the PHD promoted, designed, and conducted large parts of the first "induction week" for the more than 600 SES freshmen. This activity aimed at inviting students to learn engineering through hands-on activities from the first day of class[20 21]. Also, the papers' second-named author was the SES coordinator of the last design phase and of the implementation of the engineering reform. Currently, the entire SES, especially the IEP, is moving toward a view of engineering education that places a strong focus on students as the main drivers of the learning process.

Success cases

We suggest that one of the main benefits of the PHD's courses has been an increase in students' willingness and ability to initiate and conduct a wide variety of ambitious and relevant projects[22 23]. Among the various students' initiatives, two were selected that are emblematic due to their national impact and their direct connection with the PHD.

One of the most relevant organizations and source of pride in the Industrial Engineering Department at the University of Chile is the Industrial Engineering Student Union (IESU). The PHD collaborates with the empowerment and reactivation of the IESU, encouraging student participation, providing room for discussions, and mentorship. The IESU has promoted various initiatives that have not only local but also national impact. For example, in 2003, the IESU organized the first version of the "World Class" Conference for Chilean industrial engineering students, with great success in its first and following versions. In that year, the IESU's president and leader of this initiative was Guido Pierattini, a student who was an active beneficiary and later instructor of the PHD program. This IESU leadership initiated a new more active IESU, and Pierattini received, in 2006, the award "Outstanding Young Engineer" from the Chilean Institute of Engineers. See www.cein.cl and www.world-class.cl

In 2001 a group of students of the Introduction to Industrial Engineering course established "Construyendo Mis Sueños" ("Building my Dreams") CMS program, one of the most innovative socially oriented programs conducted by young Chileans. The CMS's main objective is to design, develop, and transfer tools and technologies that allow low-income micro

entrepreneurs to increase their managerial and productive capacity. To date, more than 2,300 micro entrepreneurs and more than 700 volunteers (mostly engineering students) have participated in the CMS program. The CMS's first four years were closely tied to the Introduction to Industrial Engineering course. See http://www.construyendomissuenos.cl

Systematization of data

During the past five years, some limited attempts to evaluate and assess the PHD impact have been made. The most significant effort was a survey sent to 1,000 former students of the Industrial Engineering course asking about their perception and evaluation of the influence of the course in their subsequent studies and first professional experiences[24]. Responses to the survey were in the 30% range, which is very high for Chilean standards.

Nearly 50% of former students selected the "High" or "Very High" response to the "Your general evaluation of the impact of the course in your training as an industrial engineer" question (the scale included: Very Low, Low, Regular, High, and Very High).

At the end of each semester, students complete a course evaluation in several dimensions. Table 1 indicates the overall students' course evaluation during 10 semesters from 2001 to 2005, comparing to the average of all IEP courses in each semester. In seven semesters the course obtained an average that exceeded the mean of the IEP.

Table 1: Comparison of the overall students' course evaluation between the Introduction to the Industrial Engineering Course and the average of all the IEP courses (Grading system from 1.0 to 7.0)

	Introduction to Industrial Engineering Course	Average of IEP courses
Fall 2001	5.7	5.9
Spring 2001	5.8	5.5
Fall 2002	5.7	5.8
Spring 2002	6.4	5.8
Fall 2003	6.3	5.7
Spring 2003	6.4	5.8
Fall 2004	6.7	6.0
Spring 2004	5.5	5.7
Fall 2005	6.6	5.9
Spring 2005	6.2	6.0

Discussions

The current work describes and reflects on the twenty-five years of a program that has survived promoting an innovative approach within a conservative and traditional engineering and

scientific environment. The PHD has influenced the industrial engineering curriculum, engaged hundreds of students in social and entrepreneurial programs and projects, making them active agent of their own learning process and slowly but steadily has expanded into other areas of the SES.

We believe that the survival and expansion of its influence justifies an effort to assess the program to identify the key factors explaining this success. To start this enquiry, we propose four hypotheses for which we have partial evidence.

- *A robust theoretical framework.* We believe that to make changes in an academic environment a strong theoretical framework is crucial, both to gain space among academics and to make it attractive to students. The fact that a National Science Prize was behind our constructivist proposal was certainly an important supporting factor.

- *Internal Leadership*. The PHD program was led by an engineer graduated from the SES as an outstanding student that started his academic career at age 22, and played a significant role in the fight against the dictatorship's attempt to intervene the SES. We propose that both the academic and political leaders' ascendance are crucial success factors for pedagogical innovation in university contexts.

- *Freedom and openness of the organizational culture.* The success of the PHD was not based only on its merits. It was possible because the SES was a place that, while as conservative as any traditional and prestigious university, is open to exploring new initiatives when they are put forward with passion and conviction. Without the long tradition of respect, admiration and promotion of plurality, academic liberty, critical thinking and pioneering thought, the PHD would have not succeeded.

- *Patience and perseverance.* Relevant changes take time, especially in higher education contexts. It took ten years to make the first significant change and, at that moment, three DIE full-time faculty members –out of a universe of 25- were involved in the initiative. Patience in facing up to challenges, opposition, criticism, and assuming and correcting mistakes was a crucial component of the PHD success.

We believe these 25 years of experience are also an opportunity to learn from many mistakes that were made in the attempt to change the traditional educational setting in engineering education. Among the mistakes, two are noteworthy:

- Confusing invention with innovation. In its undergraduate courses, the PHD tended to permanently test new activities instead of improving the originals (even those that had some success). Because of this, during some periods, we missed the focus on our "clients", the students, which is a especially serious mistake when arguing from a constructivist stand view.

- Fundamentalist temptation. The constructivist approach is attractive. Instructors and students are tempted to adopt this approach as the "New Truth." Nothing is more contradictory with the radical constructivist approach than this fundamentalist position.

Significance

We strongly believe that most of these developments are applicable to engineering education in other cultural and economic contexts. This belief is the main reason for exposing it to rigorous academic scrutiny, responding to the call in recent journals to enhance an engineering education research community that includes valuable international experiences.

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