International Journal of Engineering Education Vol. 30, No. 6(B), pp. 1525–1538, 2014
Printed in Great Britain
0949-149X/91 $3.00+0.00

Promotion of Professional Skills in Engineering Education: Strategies and Challenges*

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Basic engineering skills are not the only key to professional development, particularly as engineering problems are everyday more and more complex and multifaceted, hence requiring the implementation of larger multidisciplinary teams, in many cases working in an international context and in a continuously evolving environment. Therefore other outcomes, sometimes referred to as professional skills, are also necessary for our students, as most universities are already aware. In this study we try to methodically analyze the main strategies for the promotion of professional skills, mainly linked to actuations which directly affect students or teachers (and teaching methodologies) and which take advantage of the environment and available resources. From an initial list of 51 strategies (in essence aimed at promotion of different drivers of change, linked to students, teachers, environment and resources), we focus on the 11 drivers of change considered more important after an initial evaluation. Subsequently, a systematic analysis of the typical problems linked to these main drivers of change, enables us to find and formulate 12 major and usually repeated and unsolved problems. After selecting these typical problems, we put forward 25 different solutions, for short-term actuation, and discuss their effects, while bearing in mind our team's experience, together with the information from the studies carried out by numerous teaching staff from other universities.

Keywords: professional skills; engineering education; continuous improvement strategies

1. Introduction: Professional skills in engineering education

Successful engineering professionals depend on basic engineering knowledge, skills and abilities, such as: a profound knowledge of mathematics, physics and technology, in order to identify, model and solve engineering problems; the application of systematic working methods to design systems, components and processes, considering economic, environmental, social and human dimensions, together with the usual technical related issues; and an overall understanding of the advanced technological resources from their specific fields of dedication.

However these basic engineering skills are not the only key to professional development, particularly as engineering problems are everyday more and more complex and multifaceted, hence requiring the implementation of larger multidisciplinary teams, in many cases working in an international context and in a continuously evolving environment. Therefore other outcomes or competencies (sometimes called "soft" skills, although professional or transversal is most adequate), are also necessary for our students, as most universities are already aware. Among these competencies, some play a very special role, including: the ability to work in multidisciplinary teams, the capability of efficient (oral and written) communication, the compromise with life-long learning, creative thinking, the acquisition of ethical principles and the capability of applying them in a changing World.

The acquisition of such professional competencies has traditionally been linked to project-based learning activities and to the involvement of students in their final degree theses or projects or even considered a minor subject linked to students' first job and initial years in the industrial world. Nevertheless, in a competitive industry and with the increase of engineering universities and degrees, universities providing their students both with basic engineering knowledge and with professional competencies are nowadays essential if teaching excellence is pursued.

In addition, present methodologies for curriculum development, especially in technical universities, are based on the definition of fundamental educational objectives, achieved by pursuing the development of a series of competencies or learning outcomes (including scientific and technical knowledge, technological abilities and professional skills). Perhaps the best known methodology is the one proposed by the Accreditation Board for Engineering and Technology "ABET" that proposes the achievement of a mix of "hard" skills and "professional" skills, including: a) an ability to apply knowledge of Mathematics, Science, and Engineer-

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* Accepted 15 July 2014.

ing; 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; d) an ability to function on multi-disciplinary teams; e) an ability to identify, formulate, and solve Engineering problems; 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 lifelong learning; j) a knowledge of contemporary issues, and k) an ability to use the techniques, skills and modern engineering tools necessary for engineering practice [1].

Apart from improving student motivation and their perception that what they learn at University "is actually of some use", the promotion of all these professional skills also helps teachers become more involved in their relationship with students, to be continually up to date with new developments and renew or update subject content in line with evolving demands from Society, although all this requires considerable time and a desire to interact with students. The benefits are thus evident, however, integrating such professional competencies into the curriculum of our students, in a more controlled and adequate way, is a complex task with some uncertainties not yet solved, mainly linked to pedagogical difficulties when facing how to teach these more subjective matters, to the need of finding a balance between teaching basic and professional skills, to the necessity of using alternative assessment procedures, among others. Therefore, it is important to methodically analyze the difficulties and challenges linked to the progressive incorporation of professional skills into engineering curricula, so as to promote their advantages, reinforce some lacking aspects and limit the possible negative effects induced by the shift from more traditional teaching-learning styles, to a more global Education.

In this study we try to methodically analyze the main strategies for the promotion of professional skills, mainly linked to actuations which directly affect students or teachers (and teaching methodologies) and which take advantage of the environment and available resources. From an initial list of 51 strategies (in essence aimed at promotion of different drivers of change, linked to students, teachers, environment and resources), we focus on the 11 drivers of change considered more important after an initial evaluation. Subsequently, a systematic analysis of the typical problems linked to these main drivers of change, enables us to find and formulate 12 major and usually repeated and unsolved problems. After selecting these typical problems, we put forward 25 different solutions, for short-term actuation, and discuss their effects, while bearing in mind our team's experience, together with the information from the studies carried out by numerous teaching staff from other universities. The proposed process stands out for the possibility of carrying out systematic studies and is based on process re-engineering methodologies aimed at continuous improvement.

Some excellent previous studies have reviewed main challenges of Engineering Education for the 21st Century, highlighting the dramatically changing nature of Engineering practice [2], and have put forward the need of novel strategies, taking advantage of different drivers of change (including university business strategies, students and employers), for incorporating global skills [3]. In any case, we believe that the approach taken here contributes with new aspects, particularly regarding the implementation and continuous improvement of such strategies. We believe that the difficulties we have encountered and the proposals for solving them, even if linked to our particular experience in the School of Industrial Engineering at Universidad Politécnica de Madrid (ETSII-UPM), can be of interest and valid in many areas of Engineering.

2. Overview of strategies for promoting professional skills in engineering education

This section presents a comprehensive review of strategies for promoting professional skills in Engineering Education, making reference to groundbreaking research and studies in the field, as a starting point for our systematic analysis. For a better understanding, we group the different strategies into diverse topics, depending on the main aspect on which they focus, including: students, teachers (and teaching methodologies), environment and resources. After presenting the summary of strategies, we assess them, considering mainly their impact on the overall promotion of professional skills and their integration into the curriculum, and select the ten most relevant for further detection of challenges and solutions. The selection of strategies/drivers of change and their evaluation have been carried out by the team of authors, working as a focus group. The three authors are part of the School of Industrial Engineering' Directorate at Universidad Politécnica de Madrid with responsibilities including: internal relations between students and students associations, university extension activities, such as collaboration activities between academia and industry, employment promotion and relations with alumni, international relations and exchange programs, academic organization, development of plans of study, promotion of novel teaching-learning experiences and student progress assessment. In spite of being a reduced working group, we have intensely discussed the topics of present study for several years of collaboration and we hope that our views may be useful for other colleagues and we are sure that the presented methodology can be of help for planning similar strategies, oriented to the promotion of professional skills in other degrees of Engineering Education, always taking account of the particular aspects of each discipline and adequately adapting the methodology. In addition, we have considered several drivers of change highlighted in the different references available at the end of present study and followed the advice of a wide set of colleagues and students, who have provided personal opinions in different meetings maintained in the last couple of years.

Strategies focusing on students. Student motivation and active engagement to their own learning process is a key success factor in Higher Education, especially in Science and Engineering studies, as recognized and highlighted in several studies, reports and declarations, such as the Bologna Declaration and the subsequent related declarations from Prague, Berlin, Bergen, London, Leuven and Budapest-Vienna, aimed at the implementation of the European Higher Education Area. Making students drivers of change is perhaps the most effective part of the global strategy, for the promotion of professional skills in Engineering Education, and not necessarily the easiest element of the overall plan, as discussed in following sections.

Student associations represent their members and provide services to students, mainly focusing on free time activities, seminars and complementary lessons. Their impact on the integration of first-year and international students is relevant indeed and directly related with the promotion of student motivation and active engagement to the university life and related activities. In addition, associations are normally constituted by active students worried about contemporary issues and about their own learning process, hence contributing to students being one of the main drivers of change in Higher Education. In our opinion, the incorporation into the Engineering curriculum of some pedagogical activities developed by student associations, with the adequate overview of teaching staff, constitutes an interesting way of promoting student motivation, increasing the sense of belonging to a university, improving the curriculum by promoting the possibility of personalization, providing a more flexible answer to students' formative demands and working towards the development of several of the previously mentioned "ABET" skills. Such integration of a wide range of student activities into the Engineering curriculum presents several unresolved challenges, including the type of activities to be considered, the different alternatives for their integration, important aspects linked to the assessment of students' performance, some difficulties for the objective quantification of effort and time devoted to such activities and uncertainties connected to the life-cycle of many student associations (sometimes too short, usually dependent on personal boundaries and on the leadership of special students and their friends...). Alumni (former students) and their associations help students to maintain connections to their educational institution and fellow graduates, as well as to establish new business connections, normally through the organization of social events and through the publication of newsletters and magazines. However these alumni associations, if used as advisory boards, can be also an excellent source of ideas and initiatives for universities' continuous renewal and maintained connection with "real" (in our case industrial) life. In most cases these alumni associations are also devoted to raising funds for university and to all types of patronages, from individual activities with students, to wide scope actuation plans. Therefore, their involvement as part of the overall strategies for the promotion of professional skills is also noteworthy.

An adequate promotion of student exchange activities and of teaching-learning strategies based on international students collaborating together is, in our opinion, another key factor for successful Engineering Education, as we live in an increasingly global society. 21st Century Engineering challenges are already global and face complex phenomena, such as out-sourcing and off-shoring, open-software and open-knowledge advances, geopolitical tensions, among others [2]. Hence, the best Engineering professionals will be those able to work in international environments and to take into account socio-cultural and political factors, together with the more classic technical and economical requisites, in their decisions. The interaction between students of different countries, the participation in international experiences and the study of other languages (what is always connected with the study and comprehension of other cultures) are extremely important aspects of one's education and background. These vital experiences are essential for really significant "soft" skills, including respect for other people's culture, communication abilities, self-criticism capacity and mental flexibility.

Strategies focusing on teachers and teaching methodology. It is clear that students are the central element of the teaching-learning process and the reason for Higher Education, but it is also straightforward that teachers and their teaching methodology play a central role. In consequence, a global strategy for the promotion of professional skills must also pay close attention to changes of teachers' knowledge, abilities and attitudes.

For instance, problem- or project-based learning (typically PBL) methodologies clearly tend to motivate students to participate and become involved in their own learning process and is an excellent way of analysing whether students have acquired the basic concepts taught in the theory classes and if they are capable of applying them in real situations. These PBL experiences have proven to be effective in primary, secondary and university education and in scientific-technological, bio-sanitary, humanistic and artistic contexts [5–9]. In fact, most technical universities, before awarding the engineering degree, almost always include the standard final degree project as part of the studies, which, basically, is a PBL learning experience. The doctoral programmes are also oriented towards being completed by a doctoral thesis where the PhD students have to face solving a problem or completing a complex project. Systematic studies have enabled traditional and project-based approaches to be compared and reveal certain overall benefits, especially regarding the acquisition of professional skills, for professionals who have undergone PBL training experiences [10–11], as well as remark considerable benefits in other scientific fields [12].

However PBL experiences entail certain difficulties which can lead to educational gaps and imbalances when assessing students, if they are not borne in mind and their effects limited. An analysis of the factors of influence in the development of project-based teaching-learning experiences and proposed actions for improvement has recently been published by our team [13] and we found that several key factors were linked to teachers' pedagogical background and continued training and to their personal implication in these activities. In addition, Engineering disciplines are continuously evolving at an exponentially growing pace, so teachers' long-life learning and devotion to research activities has to be promoted, so as to allow for the adequate incorporation of new knowledge and resources to the always evolving plans of study. In some cases these novel technologies are also linked to the birth of innovative teaching methodologies [14–15], as has recently happened with the Khan Academy and the massive open online courses or MOOCs, and again the continued training of teachers is necessary. Naturally, these additional efforts have to be supported with adequate career plans, so that teachers feel supported by their institutions and imply themselves in rewarding experiences for the promotion of learning.

Strategies focusing on synergies with the environment. University-Industry collaborations have proved to be helpful for continuously enhancing the quality of commercial products, the efficiency of industrial processes and for improving the functionalities of novel devices. At the same time such contact between University and Industry is greatly beneficial for the teaching-learning process in Higher Education. It helps to renew the syllabi and the topics covered, so as to keep up with the pace of a changing industry, thus making students more prepared for their future tasks, through the promotion of professional skills. In many cases these relations promote the direct employment of students, probably by means of an assessment of their capabilities during their Masters' degree projects or theses. Such collaborations seem to be especially adequate for technical universities, as their graduates typically end up working in all kinds of industries and industrial experience is an asset for securing the most demanding (and interesting) engineering jobs.

Therefore a prosperous surrounding environment and the encouragement of synergies with the environment, by means of collaborative applied research and innovation, by supporting the creation of start-ups, spin-offs and university-industry research centers, is a determinant factor for successful engineering schools. The environment of technical universities is not just the local surrounding industrial web, which in many cases has determined the birth of specific technological centers and related degrees, but at least the whole national business and industrial network. In addition, internationalization activities help to enlarge the environment of technical universities and to provide more global and varied opportunities for students' professional development. Different strategies for empowering the relationship between academia and industry and improving what students actually learn at universities have been recently analyzed [16] and several cases of study detailing specific collaborations between technical universities and their industrial partners have been the topic of a recent special issue of the International Journal of Engineering Education [17]. In the following sections we focus more specifically on the implication of external partners, as part of the global strategy for the promotion of professional skills in Engineering Education, and try to provide possible solutions to the main difficulties and challenges derived from extra-curricular activities.

Political decisions also play a fundamental role on the fate of universities and industrial partners (and on the resources available), but it is extremely difficult and complex to count with politicians as drivers of change, because their decisions are usually unforeseen and respond to varied interests, normally different from those of students, their families and Society or even opposite to them. More accessible drivers of change, such as students and teachers, together with their direct national and international contacts, tend to be more successful for leading a change from below, as discussed in the following sections.

Strategies focusing on available resources. Adequate public and private funding and periodic special projects and actions are necessary for continuously improving Higher Education and for allowing more bachelors to continue their studies at universities, especially in technical ones, due to the relevance of laboratories, research facilities and technological resources in the overall learning process. Public or private stipendia for students, especially now that university rates are continuously increasing overall in Europe, even in public centres, are of great help and, if linked to positions in research centres and advanced enterprises, are perfect towards the promotion of professional skills.

A sufficient provision of human resources is also necessary, for supporting students in their activities, especially in the laboratories, and for helping to complete more complex, demanding and real-life project-based learning activities, including manufacturing, assembly and trials of products and systems. Support staff is determinant for providing students with services, other than conventional learning tasks in classes and labs, which also help to enhance their professional skills. Employment offices, international exchange bureaus, libraries, infrastructure and administration departments and even the canteens and cafeterias impact on students' performance and acquisition of professional skills, as these are very linked to activities outside the classrooms and laboratories. Central (rectoral) facilities, experts in information and communication technologies and supporting administrative staff are of great value for avoiding professors to be unnecessarily devoted to bureaucratic procedures, instead of devoting their time to teaching, research and strategic planning.

The patronage of industrial partners, professional associations and alumni plays also a relevant role for improving the teaching-learning processes, towards more "global" graduates, in the top technical universities of the World. Countries aiming at having universities among the most renowned rankings should focus on the social education of enterprises and professional associations, for making them aware of the relevance of working for the overall benefit of Society and not just taking decisions responding to short-term benefits.

* * *

A schematic summary of the different strategies mentioned above, highlighting the drivers of change linked to the different typical areas of actuation (students, teachers & methodology, synergies with the environment and available resources), is presented in Fig. 1.

3. Systematic detection of challenges and their causes for the promotion of professional skills in engineering education

In order to systematically detect the main challenges related to the promotion of professional skills in Engineering Education, we have analyzed the aforementioned drivers of change, evaluating their expected impact on the global strategy; their maturity of implementation (i.e. if they are already being used as drivers of change) applied to our integrated Industrial Engineering Grade and Masters' Degree at ETSII-UPM (please visit www.etsii.upm.es for additional details on program structure); and their expected difficulty of implementation, in fact the predictable complexity of promoting a concrete driver of change, as part of the global strategy. The context is interesting to highlight, as the 2013–2014 academic year will provide the first graduates of our novel Grade on Industrial Engineering and 2014–2015 will be the start point of our new Masters' Degree on Industrial Engineering, both of them adapted to the European Area of Higher Education with the Grade–Master structure, after more than 150 years of being taught, in 6 different plans of study of Industrial Engineering, as an integrated career. We expect to apply results from present study to the adjustment of the new Grade and to the final fine-tuning of the forthcoming Masters' Degree, which is currently under evaluation by the Spanish Accreditation Agency (ANECA: www.aneca.es).

The evaluation of the different drivers of change has been carried out using a survey, which was filled by the authors constituted as focus group (following the procedures from previous satisfying experiences, [16, 18]). The different drivers' expected impact, maturity and promotion difficulty have been assessed from 0 (lowest score) to 10 (highest score). Mean scores have been gathered and standard deviations are lower than 20%, which derives from having discussed together these subjects during the last years and from our similar points of view, which have been enriched by means of interviews with internal (students, teachers, researchers, administration staff) and external agents (colleagues from

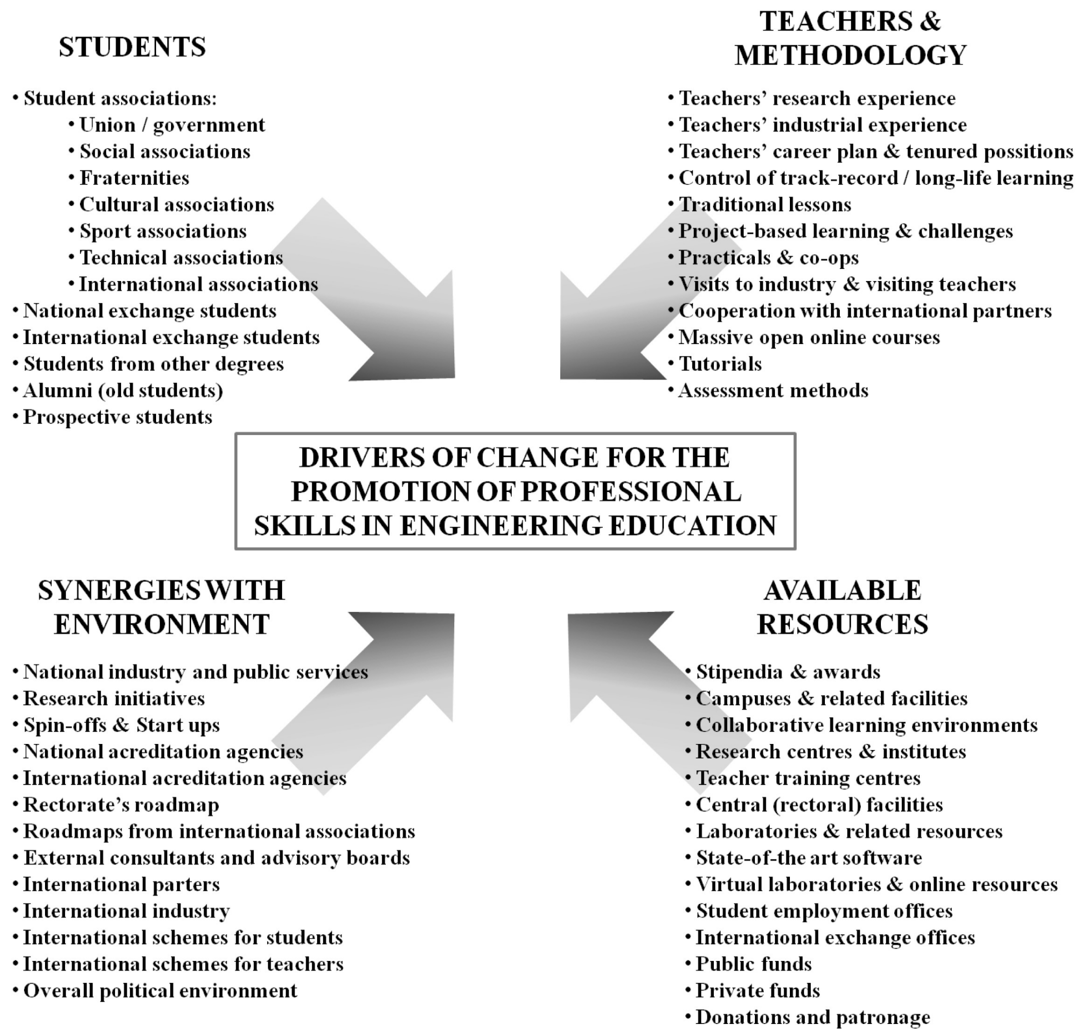

Fig. 1. Typical strategies focusing on different drivers of change for the promotion of professional skills in Engineering Education.

other universities, contacts from enterprises, professional associations, alumni . . .).

Table 1 contains the results of this analysis, showing the mean scores obtained by each of the 51 drivers of changes regarding their possible impact on the overall strategy, their difficulty of implementation and their maturity (whether they are already part of the procedures and regular activities of the institution or need additional integration efforts). They have been scored by our team according to relevance, maturity and complexity (from 0 or very easy/immature/irrelevant, up 10 or very difficult/mature/decisive). We would like to highlight the perceived impact of strategies linked to the promotion of project-based learning activities and challenges, of practicals and co-operation activities with industry, of an adequate use of assessment and of taking account of international accreditation schemes.

Figure 2 represents the impact, maturity and implementation difficulty of the different drivers of change analyzed, so as to perceive more easily the data from Table 1. In general terms, the drivers of change whose promotion has a greater impact on student acquisition of professional skills are more difficult to implement, but also more mature, as our School of Industrial Engineering has been systematically working these topics for several decades. It is also interesting to note that two aspects, considered to have the highest impacts ("Project-based learning & challenges" and "Practicals & co-ops"), are in fact not so difficult to implement, according to our experience [13]. However their maturity is still low, as we discuss further on in the following section, together with some proposals for improving their systematic incorporation to the normal procedures and activities of our institution and students.

The specific focus on "impact vs. maturity" included in Fig. 3 helps to analyze which drivers of change should be additionally pursued. Each driver of change is cited using its corresponding reference number from Table 1, so as to help with the identification of those that should be especially promoted. The main idea of our continuous improvement strategy is to concentrate on the quadrant with the more relevant aspects (those with impacts higher that 5/10) but paying special attention to those not yet adequately implemented (those with maturities lower than 5/10). For instance, aspects related to the acquisition of public and private funds, as well as tasks linked to patronage activities, are perceived as having great potential for the promotion of professional skills, even though their maturity (especially in our country) is very low. In addition, such drivers of changes are perhaps the most difficult to promote, as usually political actuations are needed. Nevertheless, in the following section we include some reflections and possible strategies for their promotion, after an adequate analysis of causes and effects linked to each of the detected limitations.

The process followed, for solving our main present limitations, is based on Ishikawa's method for the systematic search for cause-effect relations in relevant problems, and the subsequent finding of high-impact solutions, as they usually act on the

Table 1. Impact, maturity and difficulty for the promotion of different drivers of change

Code	Agent to promote	Impact	Maturity	Difficulty
1	Student union	4.00	5.67	4.33
2	Social associations	4.67	4.33	5.33
3	Fraternities	2.67	3.67	6.33
4	Cultural associations	4.33	5.00	5.00
5	Sport associations	3.67	4.33	4.67
6	Technical associations	7.67	5.33	3.33
7	International associations	7.33	5.67	4.67
8	National exchange students	3.67	5.00	4.67
9	International exchange students	5.33	6.67	4.67
10	Students from other degrees	4.00	2.33	6.33
11	Alumni (old students)	6.33	3.67	6.33
12	Prospective students	3.67	1.67	7.67
13	Teachers' research experience	6.67	5.33	7.33
14	Teachers' industrial experience	7.33	5.00	6.33
15	Teachers' career plan & tenured positions	5.33	5.00	5.33
16	Control of track-record/long-life learning	4.67	3.33	7.00
17	Traditional lessons	5.00	8.67	3.33
18	Project-based learning & challenges	9.67	5.67	5.67
19	Practicals & co-ops	9.00	5.00	5.67
20	Visits to industry & visiting teachers	7.67	4.67	5.67
21	Cooperation with international partners	7.00	4.00	7.67
22	Massive open online courses	6.00	4.00	4.33
23	Tutorials	5.33	6.00	3.67
24	Assessment methods	7.33	5.67	4.33
25	National industry and public services	7.33	6.00	8.33
26	Research initiatives	6.67	5.67	8.00
27	Spin-offs & Start ups	7.33	5.33	8.33
28	National accreditation agencies	5.33	6.00	8.33
29	International accreditation agencies	7.00	8.00	8.00
30	Rectorate's roadmap	5.33	2.67	9.00
31	Roadmaps from international associations	4.00	3.00	7.00
32	External consultants and advisory boards	6.00	5.67	7.00
33	International partners	6.33	5.33	7.67
34	International industry	7.00	5.00	8.00
35	International schemes for students	6.33	5.33	7.67
36	International schemes for teachers	7.33	5.00	8.33
37	Overall political environment	8.33	2.67	9.00
38	Stipendiary & awards	7.33	4.67	8.33
39	Campuses & related facilities	7.00	4.67	8.33
40	Collaborative learning environments	7.67	5.67	7.00
41	Research centres & institutes	6.00	7.00	8.33
42	Teacher training centres	7.67	5.67	7.00
43	Central (rectoral) facilities	5.33	4.67	8.00
44	Laboratories & related resources	8.33	5.33	7.33
45	State-of-the art software	7.00	5.33	6.67
46	Virtual laboratories & online resources	8.33	5.00	6.67
47	Student employment offices	7.33	6.33	6.67
48	International exchange offices	6.33	6.00	7.00
49	Public funds	8.33	3.00	9.67
50	Private funds	8.33	3.33	8.67
51	Donations and patronage	8.67	2.67	8.33

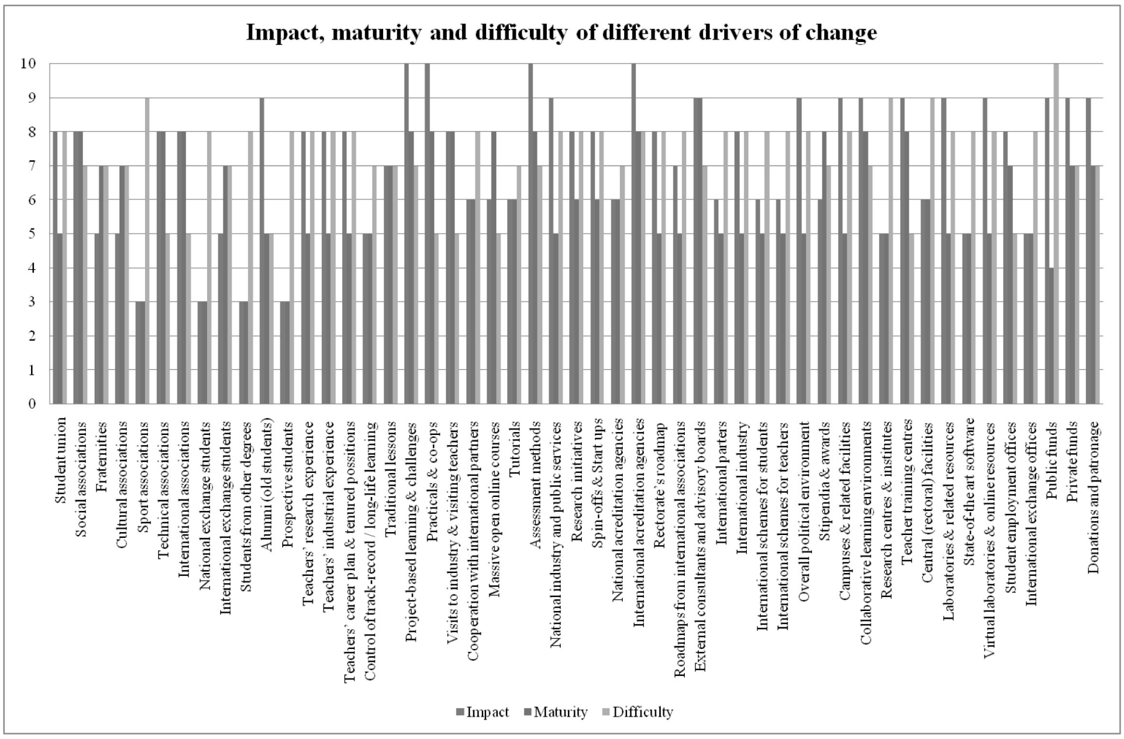

Fig. 2. Impact, maturity and difficulty of different drivers of change.

common causes of different problems. The process has been previously applied by our team in the search for solutions linked to teaching-learning processes and methodologies [13, 18]. In this study, the development of the different cause-effect diagrams (Figs. 4–10) is based on the collaborative discussion between the authors trying to write down, for each of the main problems detected, at

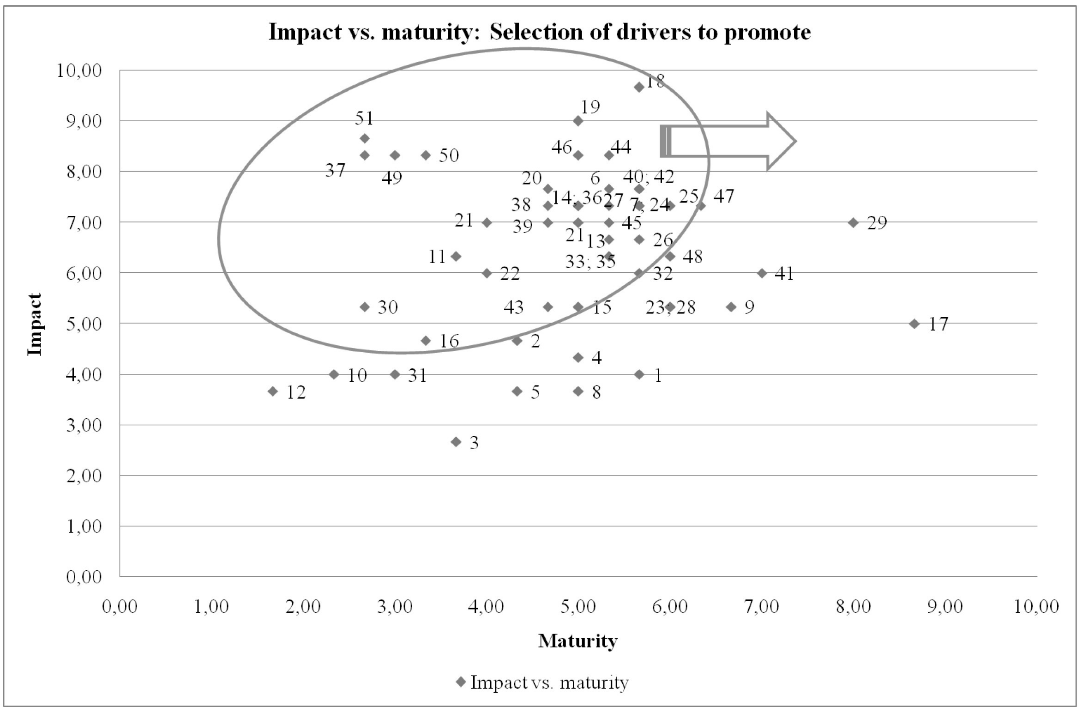

Fig. 3. Impact vs. maturity: Selection of drivers to promote. The numbered drivers of change correspond to the notation from Table 1.

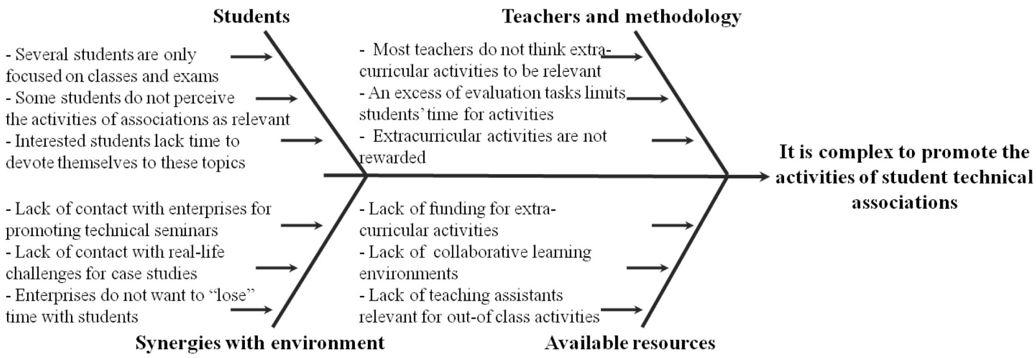

Fig. 4. Cause-effect diagram of the problem: "It is difficult to promote the activities of student technical associations".

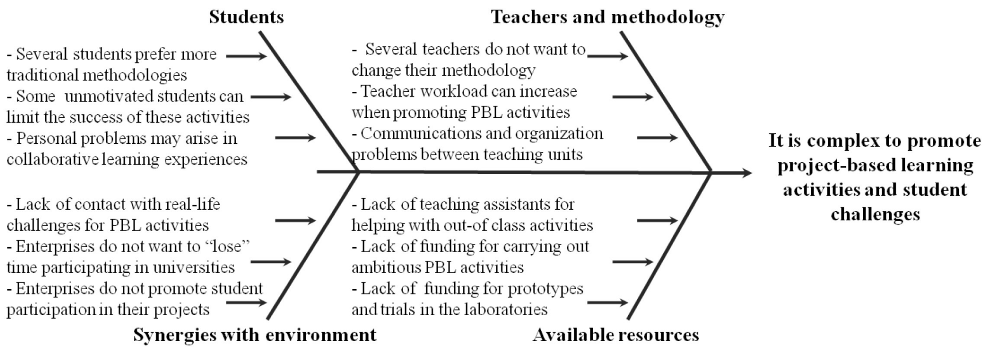

Fig. 5. Cause-effect diagram of the problem: "It is difficult to promote project-based learning activities and student challenges".

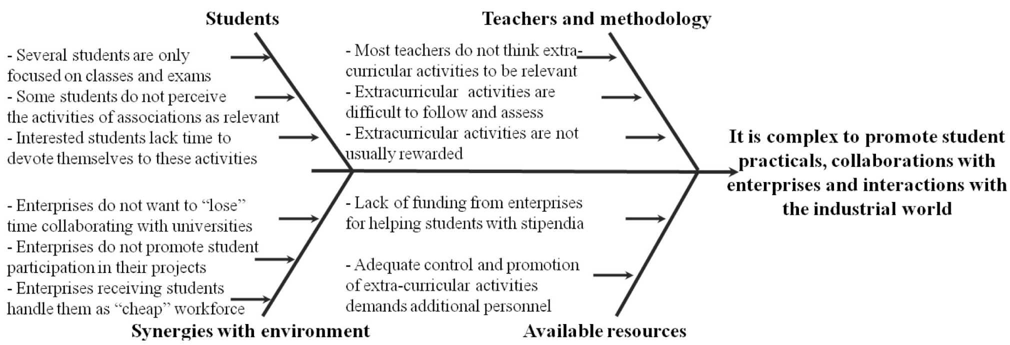

Fig. 6. Cause-effect diagram of the problem: "It is difficult to promote student practicals, collaborations with industry (co-ops) and additional interactions with industrial world".

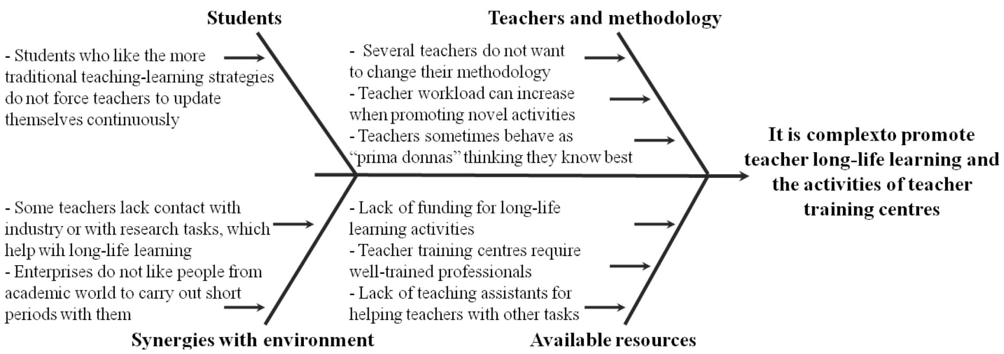

Fig. 7. Cause-effect diagram of the problem: "It is difficult to promote teacher long-life learning and the activities of teacher training centres".

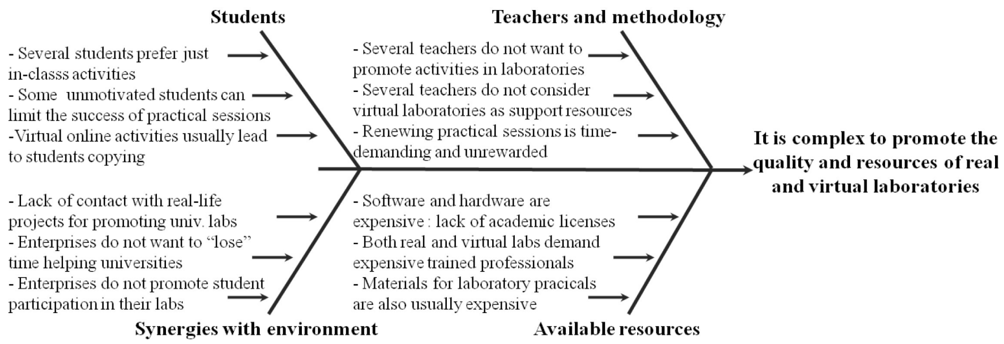

Fig. 8. Cause-effect diagram of the problem: "It is difficult to promote the quality and resources of real and virtual laboratories".

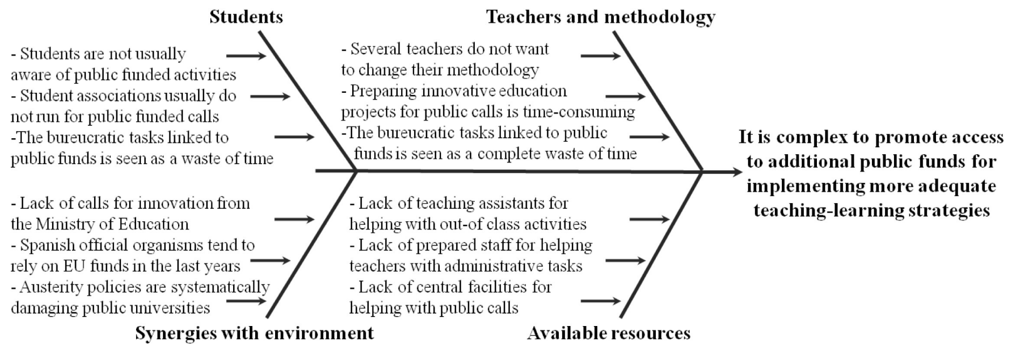

Fig. 9. Cause-effect diagram of the problem: "It is difficult to promote access to additional public funds for implementing more adequate teaching-learning strategies".

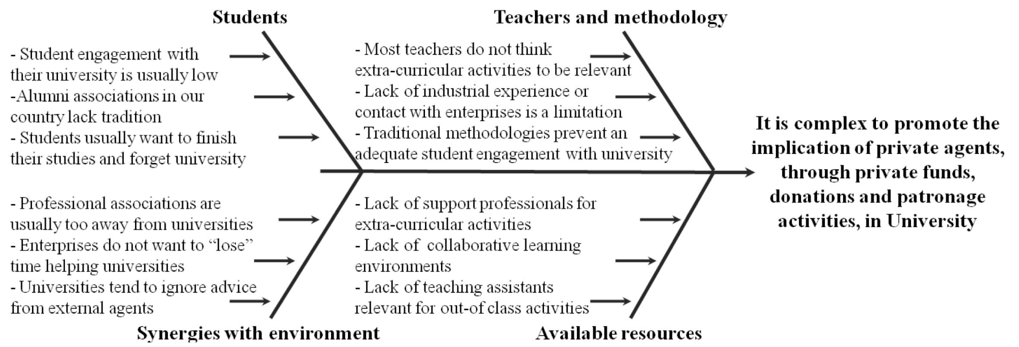

Fig. 10. Cause-effect diagram of the problem: "It is difficult to promote the implication of private agents, through private funds, donations and patronage activities, in University".

least three causes linked to each one of the four main aspects ("students", "teachers and methodology", "synergies with environment" and "available resources"), as further detailed in the following section.

4. Proposals for solving the main problems linked to the different strategies and related discussion

In our Centre, the more relevant drivers of change, which still require special efforts towards their adequate interaction with the regular teaching-learning procedures and activities, hence also enabling their plenty support to the overall strategy for the promotion of professional skills, are listed below in Table 2. The list includes those drivers with an impact above 7.5/10, all of them with low maturity values in our case, in order to start working on the more relevant and urgent limitations. From the list, after adequate aggregation of some related drivers of change and after neglecting those ones, upon which we cannot act (i.e. "overall political environment", which truly is beyond our current range of action), we highlight those 7 aspects we would like to study specially in depth.

Table 2. Detected relevant drivers of change needing special implementation efforts

Problem code	Agent to promote	Impact	Maturity
A	Student technical associations	7.67	5.33
B	Project-based learning & challenges	9.67	5.67
C	Practicals & co-ops	9.00	5.00
	Visits to industry & visiting teachers	7.67	4.67
–	Overall political environment	8.33	2.67
D	Teacher training centres	7.67	5.67
E	Laboratories & related resources	8.33	5.33
	Virtual laboratories & online resources	8.33	5.00
F	Public funds	8.33	3.00
G	Private funds	8.33	3.33
	Donations and patronage	8.67	2.67

Subsequently, we develop different cause-effect diagrams for the problems: "*the integrated driver of change "X" is not sufficiently mature*" (with X = A . . . G), so as to find the problematic causes and propose solutions in a more systematic way, after adequate reformulation of the different problems and limitations. The problematic causes and related solutions are also grouped using again the four main aspects ("students", "teachers and methodology", "synergies with environment" and "available resources") on which they focus. The different cause-effect diagrams are depicted below in Figs. 4–10, showing at least 8 main causes for the different problems, on which we are focusing, for detecting the most relevant causes (those that affect different problems). Afterwards, the main limitations, proposed solutions and additional tools for checking their progress are summarized in Table 3, and additionally discussed in subsections 4.1 to 4.3. It is important to note that some of the problems highlighted are endemic to Spanish higher education institutions and usually much more common in Europe than in North America, so several proposed solutions may be state-of-the-art in other countries. In any case we hope the followed process and some of the ideas presented may be of interest for readers worldwide.

4.1 Regarding students

As previously analyzed, promoting student motivation is perhaps the key factor for successful teaching-learning experiences in student-centred universities. Schedule limitations, due to an excessive employment of traditional methodologies mainly focused on master classes and exams, prevent students from plenty fulfilling their expectations on university life. Most activities of student associations, if not adequately considered, supported and admitted as part of the curricula by the academic staff, may just not be carried out. Our proposal and current line of action is to prepare a compilation of interesting educational activities (i.e. challenges, seminars, international workshops...) organized by students themselves (mainly by technical student associations) and incorporate them as part of our plans of studies, with ample academic overview, at least as part of modules especially devoted to the acquisition of professional skills.

In this way, students will feel also more supported by their teachers and their engagement with university may improve, which is also a significant aspect for the increased success of alumni associations, typically lacking tradition in our country. If the most active students are thus oriented to collaborate in associations, they will also end up engaged to alumni associations and help to incorporate more relevant actions, aimed at professional development, into these (professional) clusters. Hence universities will have additional powerful ways of interacting with environment and increasing their projection in Society.

4.2 Regarding teachers and methodology

Academic staff in our country is overwhelmed with bureaucratic tasks and needs additional stimuli for continuously upgrading the teaching-learning methodologies and for compromising with lifelong learning, including their participation in research and innovation activities, as well as their visiting other relevant research centres and industries for formation periods. Counting with the help of teaching assistants (a very limited figure in our universities) may be a good strategy towards these purposes, as well as for generational shift in grown old universities.

Additional help from central facilities and administration staff is also compulsory, for enabling academic staff to concentrate on teaching and research, thus helping also academics to interact with the industrial environment by means of joint innovation projects, for which they have currently reduced time. These synergies with enterprises could be also promoted if collaboration activities were adequately assessed for tenure track as, at present, our National Accreditation Office (ANECA) mainly considers scientific publications for promotion, leaving teaching and industrial experience in a

Table 3. Table summarising the main difficulties and problems detected for the promotion of professional skills and some proposed solutions for greater success

Problems	**Proposed solution**	**Tools to check progress**
Students:		
Students do not have time for extra-curricular activities (associations, challenges, co-ops...).	Include extra-curricular activities in the curriculum and assess them.	Number of credits linked to extra-curricular activities.
	Limit the number of project-based learning activities carried at once.	Number of PBL activities per term.
	Limit the number of intermediate assessment trials.	Number of exams per term.
Alumni associations lack tradition.	Focus the activities of alumni associations into relevant actions for professional development.	Number of technical courses, number of jobs offered.
	Promote patronage from alumni for current student activities.	Number and type of funded activities.
Low engagement with University.	Improve the relationships between teachers and students.	Number of joint activities carried out.
	Involve students in research and innovation projects from the beginning.	Number of stipendia offered.
	Promote the activities of student associations.	Number of activities entirely devoted to students.
Teachers/methodology:		
Lack of time for changing methodologies.	Provide help from central facilities for bureaucratic tasks and reduce such tasks.	Number of hours devoted to the less relevant actuations.
	Promote the incorporation of teaching assistants and research fellows into teaching.	Number of assistants incorporated.
Lack of industrial/research experience.	Require industrial experience, research activities or stays in research centres for tenure track.	Accreditation agencies.
	Provide help from central facilities for bureaucratic tasks linked to research and innovation.	Number of research-innovation projects.
Lack of compromise with lifelong learning.	Reduce the number of hours devoted to purely bureaucratic activities.	Number of hours devoted to the less relevant actuations.
	Promote the incorporation of teaching assistants and research fellows into teaching for extra time.	Number of assistants incorporated.
Synergies/environment:		
Limited academia-industry contact.	Promote joint research and innovation projects with industry and increase their relevance for tenure track.	Number of research-innovation projects.
	Promote joint teaching-learning activities within the curricula.	Lessons from industry in university and vice versa.
Professional associations are far from universities.	Include opinions and proposals from associations when developing novel plans of study.	Advisory board meetings.
	Promote patronage activities via public recognition.	Funded activities.
Austerity policies damage public university.	Promote joint research and innovation projects with industry and increase their relevance for tenure track.	Number of research-innovation projects.
	Promote patronage activities via public recognition.	Funded activities.
Available resources:		
Lack of teaching assistants.	Resort to patronage activities and to rewarding stipendia working within joint research projects with industry.	Number of assistants incorporated.
Lack of adequate staff to handle bureaucracy.	Focus on systematic resource management.	Improved performance, surveys and questionnaires.
	Involve the staff from central facilities in lifelong learning.	Number of courses offered.
Lack of stipendia and resources for labs and extra-curricular activities.	Involve enterprises in patronage activities, after their implication in successful joint projects.	Funds raised.
	Promote patronage activities via public recognition.	Funded activities.

second place. These proposals are linked to the ones detailed in the following subsection.

4.3 Regarding synergies with environment and available resources

Education is an economically and socially productive investment and educational systems should continuously improve in quality, in efficiency and in equality of opportunity, if they are to continue serving as important instruments for improving the national economy [19]. To this end public as well as private resources should be combined: on the one side, austerity policies lead to several social factors competing for the same funds and prevent social progress [20–21]; on the other side, heavy subsidization of higher education may be carried out at the expense of primary schooling, which is unacceptable [19]. Therefore, universities must take a step forward and systematically search for additional funding from enterprises, industry, alumni, either generated in collaborative projects, or via patronage activities, in order to complement the public resources available (whose promotion is well beyond the possibilities of academic staff).

In our country a cultural shift is needed, as we lack tradition of patronage activities, but some simple solutions for an adequate start include the promotion of student engagement with their universities, the implementation of alumni offices for a systematic encouragement of relations between universities, professionals and professional associations, the public recognition of special compromise with our teaching-learning institutions, as well as some of the solutions already mentioned in previous subsections. All this, together with a more systematic resource management with the help of lifelong trained staff, can be indeed of great help. The resources thus generated may be ideal for complementing strategies for the promotion of professional skills, by providing support to student scholarship programs, to the recruitment of teaching assistants and to the acquisition of materials and equipments for laboratories and for extra-curricular activities.

5. Conclusions

In this study we have tried to methodically analyze the main strategies for the promotion of professional skills, mainly linked to actuations which directly affect students or teachers (and teaching methodologies) and which take advantage of and try to improve the environment and available resources. We have discussed several actuations for improvement, many of which we are already implementing in our School of Industrial Engineering. Some strategies linked to the promotion of alternative non-austerity policies and cultural changes are beyond our capabilities, but the implementation of some simple proposals with remarkable impact, obtained by direct application of the re-engineering methodology, is already on the way and providing interesting results. We hope that the reflections in this work may be of use for teachers in many fields of Engineering who wish to apply this kind of strategies for the promotion of professional skills and design specific actions for their subjects or plans of study.

Acknowledgements—We acknowledge support from Universidad Politécnica de Madrid, through its "2012-2013 Call for Educational Innovation Projects", especially for the granted project "Proyecto Educativo de Centro: ETSI Industriales". We acknowledge interesting discussions with our colleagues and students, as well as reviewers' advices, which have been of great help.

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