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Engineering Education for All: Strategies and Challenges*

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The path to the future requires the best possible trained engineers for further developing and mentoring the technological advances that are reshaping the present. Such advances may be the keys for facing the challenges ahead, including the population outgrowth, the climate changes and a global need for sustainability and responsible management, which probably will not come from traditional politics, but from people capable of building bridges between the mentioned advances and of handling them ethically. All this brings us to the topic of "Engineering Education for All". If the "engineers of the future" are to be key players in solving current challenges of Mankind, we will need the most talented and motivated ones, regardless of their social background and economical status. In this study we try to methodically analyze the main strategies for the promotion of "Engineering Education for All", 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 60 strategies, we focus on the 10 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 10 major and unsolved problems. After selecting these typical problems, we put forward 24 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 colleagues.

Keywords: engineering education; continuous improvement strategies; education for all

1. Introduction: engineering education for all

The mission of University is to contribute to the progress of Society by pursing the creation, preservation and dissemination of knowledge. Creation of knowledge is achieved by means of research and development tasks; preservation and dissemination are promoted by teaching-learning activities for supplying the professionals of the future, by the generation of patents, prototypes and publications and by technological transfer and innovation actions. This view about the mission of University is shared, with slight differences, by the most relevant research intensive universities worldwide and clearly constitutes a very complete and formal description of what modern universities should focus on.

However, we can think of a more emotional mission of University, linked to its main players and to its more magical essence: students and the relations between students and professors respectively. Placing students in the central place of any analyses carried out in relation with universities' past, present and future always provides an interesting point of view. Clearly, research activities at universities, without students taking part in or benefiting from them, would be out of focus. The same happens to preservation and dissemination activities. A more romantic mission of University, placing students in the central place, could claim: "To provide students with the intellectual background, operational resources and social environment, in order to help them achieve their dreams, towards a successful personal and professional life".

According to the UNESCO Universal Declaration of Human Rights, "everyone . . . is entitled to realization . . . for his dignity and free development of his personality" and "Education shall be directed to the full development of the human personality . . .". In addition, " . . . technical and professional Education shall be made generally available and Higher Education shall be equally accessible to all on the basis of merit" [1]. In consequence, taking account of our formulation of the mission of University, Higher Education is directly linked to an easier access to the fulfillment of personal dreams and deeply rooted within the basics of Human Dignity. Universal access to University, without consideration of social status, race, religion, political opinions, sex or sexual orientation, is a relevant issue, which should be further studied and pursued for a fairer global civilization. Such "Democratization of University" can provide similar results as those from democracies operating on healthy patterns. Rephrasing a description of democracies by the Nobel Prize winner Al Gore [2], the Democratization of University can produce (from the interaction of people with different perspectives, predispositions and life experiences)

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emergent wisdom and creativity, can carry the dreams and hopes for the future and may provide us with the "last best hope" to find a sustainable path for Humanity through the most disruptive and chaotic changes civilization has ever confronted.

The path to the future requires the best possible trained engineers for further developing and mentoring the technological advances that are reshaping the present, including the biotechnological revolution, the planet-wide communication grids, the advent of nanotechnology and the emergence of artificial intelligence, among others. Such advances may be the keys for facing the challenges ahead, including the population outgrowth, the climate changes and a global need for sustainability and responsible management, which probably will not come from traditional politics, but from people capable of building bridges between the mentioned advances and of handling them ethically. All this brings us to the topic of "Engineering Education for All", to its related challenges and to the strategies for its systematic promotion. If the "engineers of the future" are to be key players in solving current challenges of Mankind, we will need the most talented and motivated ones, regardless of their social background and economical status.

In fact, modern Engineering degrees combine a necessary in-depth theoretical focus on basic disciplines of science and technology, with more applied activities, aimed at the promotion, not only of technical skills, but also of fundamental professional outcomes, so as to educate successful Engineering professionals. Among the typical applied actions in Engineering Education we can cite: practicals in laboratories with state-of-the-art technologies, project-based learning activities, collaborations in research projects, visits to industrial environments, professional practices, and the usual final degree theses. Such combination between theoretical and practical teaching-learning strategies helps to configure interesting curricula for building well-trained professionals, but requires important dedication from a teaching staff in continuous methodological recycling, as well as well-equipped laboratories and research centres with advanced technologies. All this makes Engineering studies more expensive, than those from other disciplines, which usually directly affects tuition costs and, in many cases, prevents talented aspirants from studying Engineering.

In recent years, the concept of "Engineering Education for all", meaning "Engineering studies available for all those loving Engineering, without taking account of their social class and economical status", is in the middle of universal changes and should be analyzed in further detail:

1. On the one hand, public universities, which traditionally aim at the universal access to knowledge, are facing extremely harmful spending restriction policies (mainly all over Europe), which importantly increase tuition costs and limit, not only the access to Higher Education, but also the positive impact of high-quality teaching and research.
2. On the other hand, some of the most world-renowned (as well as expensive and exclusive) private universities have established new ways of freely opening their courses to all those showing interest for them, mainly in the form of massive open online courses and extracurricular activities, which constitutes an unseen knowledge democratization process. At the same time, increasing university-enterprise collaborations are also helping to promote the access to high-quality Engineering Education, with attractive dedication and mobility schemes for students. In addition, developing countries rely on appropriate educational strategies to fight poverty and inequality and many technological universities are key players in such a scene.

In connection with the aforementioned changing environment, the UNESCO "Education for all" Movement proposed in year 2000, six goals (connected mainly to promoting an equitable access to Education, to eliminating class and gender disparities and to improving lifelong learning), which should be met in year 2015, so as to provide quality education for all children, youth and adults [3–4]. Much has been achieved, but there is still a long way ahead of us, especially in such a complex and technology-dependent discipline as Engineering. Right now, having just left year 2015 behind, it is important to analyze and exchange success strategies and cases, so as to promote "Engineering Education for all" and to align such a relevant concept with the Millennium Development Goals, as engineers must play a very relevant role for enabling the fulfillment of such objectives. It is necessary to focus on aspects such as strategies for promoting equitable access to Engineering worldwide, integral actuations linked to complete program implementations in developing countries, case studies aimed at eliminating class and gender disparities in Engineering Education, profitable public-private partnerships and fundraising activities, promotion and assessment of professional skills, comparative studies of the performance of Engineering Education systems worldwide, public and private schemes and equitable access to Education and good practices for the promotion of sustainability.

In this study we try to methodically analyze the main strategies for the promotion of "Engineering Education for All", 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 60 strategies (in essence aimed at promotion of different drivers of change, linked to students, teachers, environment and resources), we focus on the 10 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 10 major and usually repeated and unsolved problems. After selecting these typical problems, we put forward 24 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, which has been previously applied for the promotion of professional skills [5], for the improvement of project-based teaching-learning activities [6] and for the overall enhancement of the teaching-learning process [7]. Some excellent previous studies have reviewed main challenges of Engineering Education for the 21st Century, highlighting the dramatically changing nature of Engineering practice [8], and have put forward the need of novel strategies, taking advantage of different drivers of change (including university business strategies, students and employers), for educating the engineers of the future [9]. In any case, we believe that the approach taken here contributes with new aspects, particularly regarding the implementation and continuous improvement of such strategies, but taking into account the concept of "Engineering Education for All" and aimed at the promotion of accessible Engineering studies to all those talented and motivated students. 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 "engineering education for all"

This section presents a comprehensive review of strategies for promoting the previously explained concept of "Engineering Education for All", 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. 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 authors have a combined teaching experience of more than 50 years in different Engineering fields, have taken part in more than 20 teaching innovation projects and in more than 50 public and private research and innovation projects and have been involved in 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 "Engineering Education for All", 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. After presenting the summary of strategies, we assess them in the following Section, 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.

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 [10] 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 "Engineering Education for All".

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. 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. It is also important to point out that student associations help to support ethnical, religious or cultural minorities and to promote the integration of students from diverse backgrounds into university life. As most activities are free of charge (including the formative ones), student associations clearly help to promote "Engineering Education for All". Apparently simple activities, such as the organization of "international cooking days", "creativity days" or "female engineering competitions", may help to integrate traditionally under-represented groups of students. The collaboration of student associations with non-governmental organizations and with high schools from low-income neighbourhoods may be also a key for promoting outreach and an equitable access to Engineering 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 and providing a more flexible answer to students' formative demands. In some cases, a reduction of tuition fees may be even possible, by taking account of free formative activities, performed in an informal way among pairs and following co-education principles [11], as part of the Engineering curriculum. 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 from low-income backgrounds, to wide scope actuation plans. Therefore, their involvement as part of the overall strategies for the promotion of "Engineering Education for All" is also noteworthy.

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 "Engineering Education for All" must also pay close attention to changes of teachers' knowledge, abilities and attitudes. In fact, so far, the most relevant and successful strategies for the "Democratization of University" have been a direct consequence of the visions and efforts of professors and teams of professors, even if supported by recent technological advances, as described under these lines and along the whole study.

Regarding the democratization of university and the promotion of universal access to knowledge, it is important to highlight new teaching-learning paradigms [12, 13] linked to massive open online courses (MOOCs) and open-access internet-based academies (being the Khan Academy a remarkable pioneer), as well as the recent open-access publication schemes in engineering research, which are re-shaping Higher Education and helping to promote the concept of "Engineering Education for All". Even without completely resorting to a 100% internet-based e-Learning methodology, it is possible to optimize the ratio "learning vs. cost" in engineering studies by a progressive incorporation of e-Learning and b-Learning methodologies, which also provide an additional degree of flexibility to students with part-time jobs. This shift towards technology-enhanced methodologies can only be promoted with the active involvement of teachers. It is also the personal decision of teachers to opt for open-source software and open-access learning materials, as support to their subjects. Considering that the typical cost of a basic algebra handbook for freshmen lays between 50€ and 70€ and that a complete plan of studies usually involves more than 50 subjects, the employment of open-access learning materials may be a key aspect for students with low-incomes.

Changes to engineering curricula are also mainly discussed among teachers and driven by them, although within a legal common framework and basic principles usually set down by the Ministry of Education (at least in our country). In consequence, revising the curricula towards more flexible schemes, capable of taking into account the professional experience or the involvement in extra-curricular activities as credits, is also in the hands of teachers. These changes would help students to combine work and study, which is fundamental for the promotion of "Engineering Education for All". Furthermore, as teachers are also the drivers of research, orienting research activities towards more social purposes, including the universal access to Education, is also a personal decision, whose potential impacts cannot be underestimated. Naturally, these additional teachers' 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.

The beneficial consequences of collaborations between teachers, students and student associations, for the promotion of "Engineering Education for All", must be also taken into consideration. The organization of open-access days, visits to high-schools and vocational fairs, short-term stays in university for high-school students, among other activities aimed at orienting students and making parents aware of the relevance of Higher Education, are clearly more successful if performed collaboratively between teachers and students.

In the last academic years, senior students constitute also a great help for teachers in research projects, which may fund their participation and help them with stipends for finishing their studies and even for mobility activities. Senior students, with the adequate guidance of teachers, can be involved also as assistants for practical sessions or as mentors for freshmen and for "engineering year zero" courses, which is not just beneficial for the younger students receiving the help of the older ones, but also for these, which promote their social and communication skills and organizational abilities. The systematization of these activities and even their connection with credits of the engineering curricula also helps to optimize the ratio "learning results vs. costs" in technical universities.

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 both technical and professional skills. In many cases these relations encourage 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 [5] 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 [14].

Some direct consequences of university-enterprise collaboration for the promotion of an equal access to engineering studies and for encouraging "Engineering Education for All" include: the possibility of paid internships for students with low-resources, the possibility of linking credits of the curricula with internships in enterprises and technological centres, the promotion of funded mobility linked to working experience (i.e. Erarmus Plus' Traineeships Program), among others.

In the following sections we focus more specifically on the implication of external partners, as part of the global strategy for the promotion of "Engineering Education for All", and try to provide possible solutions to the main difficulties and challenges derived from the need of economical support required by several motivated and talented students from low-income backgrounds. 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 also 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. Access to design, simulation, prototyping and testing resources is relevant for the promotion of complete project-based learning experiences [5, 15]. Public or private stipends 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 the "Engineering Education for All" concept.

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. Employment offices, international exchange bureaus, libraries, infrastructure and administration departments and even the canteens and cafeterias impact on students' performance. 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 help of senior students, which may also receive stipends and credits according to the time devoted, and knowledge and abilities acquired, especially for support tasks in labs and for advising younger students, must not be neglected.

Regarding technological resources and infrastructures, it is important to highlight the benefits of open-source software and open-source "do-it-yourself" manufacturing technologies, such as the "RepRap" fused deposition modelling 3D printers [16]. Interesting initiatives such as the "Build my lab contest", in which students participate in competitions (with eventual recognition of credits) for constructing learning resources, which last for subsequent generations, are enabling low-cost, easy and rapid implementations of technologies for improving the teaching-learning process in universities worldwide [17]. The advent of low-cost electronic resources, such as Arduino microprocessors [18], as well as the progressive employment of smart phones, as technological resources with the capabilities of miniaturized computers, which can be used as multi-purpose lab instruments (if the adequate apps are used) [19], constitute excellent approaches for the optimization of the ratio "learning results vs. costs". Projects linked to the implementation of low-cost but versatile product development labs in developing countries are also a source of inspiration towards an "Engineering Education for All" [20]. Again, the combined efforts of teachers and students for improving their own environment stand out as drivers of change.

Finally, the patronage of industrial partners, professional associations and alumni plays also a relevant role for improving the teaching-learning processes, towards more "global" graduates, contributing as well to the promotion of "Engineering Education for All". 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, taking also account of the importance of promoting equal opportunities, 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 "engineering education for all"

In order to systematically detect the main challenges related to the promotion of "Engineering Education for All", we have analyzed the aforementioned drivers of change, evaluating their expected impact on the global strategy; their maturity of implemen-

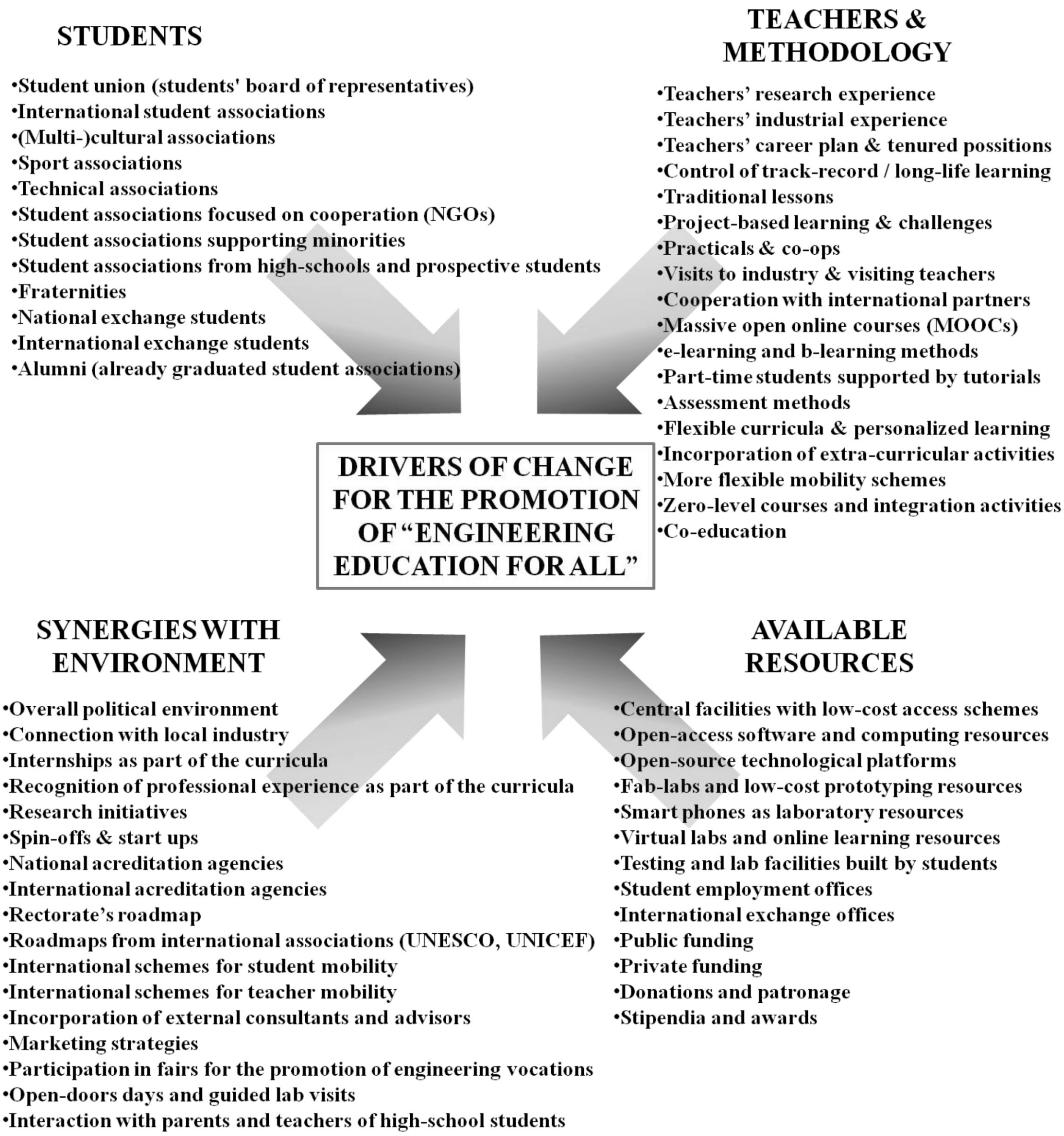

Fig. 1. Typical strategies focusing on different drivers of change for the promotion of professional skills in Engineering Education.

tation (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 has just provided the first graduates of our novel Grade on Industrial Engineering and 2015–2016 will provide first masters of Science 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 these new plans of study.

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, [5–7]). 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 other universities, contacts from enterprises, professional associations, alumni . . .). Tables 1 and 2 contain the results of this analysis, showing the mean scores obtained by each of the 60 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 employment of project-based learning activities and challenges, the connection with the industrial environment, the generation of spin-offs and start-ups, the use of open-source/access software and resources, the promotion of mobility and international relations and the encouragement through patronage and public—private funding.

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 Tables 1 and 2. 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 three aspects, considered to have the highest impacts ("open-access software", "open-source technological platforms" and "low-cost manufacturing resources"), are in fact not so difficult to implement, according to our experience. However, their maturity is still low, as we discuss further on in the following section.

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 Tables 1 and 2, 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

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

Code	Agent to promote (driver of change)	Mean Impact	Mean Maturity	Mean Difficulty
1	Student union (students' board of representatives)	5.75	4	6.25
2	International student associations	7.25	4.5	5.75
3	(Multi-)cultural associations	7	5	5.75
4	Sport associations	6.5	6.25	4
5	Technical associations	7.5	5.5	5
6	Student associations focused on cooperation (NGOs)	6.75	5.25	5
7	Student associations supporting minorities	5.5	3.25	6.25
8	Student associations from high-schools and prospective students	7	3.5	5.75
9	Fraternities	4.5	2.25	7
10	National exchange students	6	6	4.5
11	International exchange students	7.5	8.25	5.75
12	Alumni (already graduated student associations)	7.75	5.5	6.5
13	Teachers' research experience	7.5	8	4.75
14	Teachers' industrial experience	8*	5.5	6.5
15	Teachers' career plan & tenured positions	7.5	4.75	6.25
16	Control of track-record/long-life learning	7.75	4.25	7
17	Traditional lessons	6	8.75	2
18	Project-based learning & challenges	8.5**	6.5	4.25
19	Practicals & co-ops	8*	6.5	5.25
20	Visits to industry & visiting teachers	8.5**	6.5	3
21	Cooperation with international partners	7.75	5.75	4.75
22	Massive open online courses (MOOCs)	7.75	4.25	4.5
23	e-learning and b-learning methods	8.25*	5.5	4
24	Part-time students supported by tutorials (i.e. UNED)	7.25	4.75	4.5
25	Assessment methods	6	6.5	6
26	More flexible curricula for personalized learning	6	5	5.75
27	Incorporation of extra-curricular activities to the curricula	7.5	5.25	5
28	More flexible mobility schemes	7.5	5.25	6.5
29	Zero-level courses and integration activities	7.5	6	5.25
30	Co-education (older students helping younger ones)	6.75	5	5.25

Drivers of change linked to students, teachers and teaching methodologies.
(*** Outstanding impact; ** very relevant impact; * important impact).

Table 2. Impact, maturity and difficulty for the promotion of different drivers of change

Code	Agent to promote (driver of change)	Mean Impact	Mean Maturity	Mean Difficulty
31	Overall political environment	8.5**	3.75	9.5
32	Connection with local industry	9.5***	4.75	6
33	Internships as part of the curricula	8.5**	6.25	5.25
34	Recognition of professional experience as part of the curricula	8*	5	4.25
35	Research initiatives	7.5	5.75	4.75
36	Spin-offs & start ups	9.25***	5	6.25
37	National acreditation agencies	6	6.25	5.5
38	International acreditation agencies	6.75	6	5.75
39	Rectorate's roadmap	6.25	5.5	5.25
40	Roadmaps from international associations (UNESCO, UNICEF. . .)	6.25	5.25	5
41	International schemes for student mobility	9.25***	7.5	5
42	International schemes for teacher mobility	8.5**	5.75	5.25
43	Incorporation of external consultants and advisors	6.5	3.75	4.5
44	Marketing strategies	6.25	3.75	6.25
45	Participation in fairs for the promotion of engineering vocations	7.75	4.25	4.75
46	Open-doors days and guided lab visits	7.25	5	3.25
47	Interaction with parents and teachers of high-school students	8.5**	3.25	4.5
48	Research facilities with low-cost access schemes	8.5**	2	6.5
49	Open-access software and computing resources	9**	4.5	3.75
50	Open-source technological platforms (i.e. Arduino . . .)	9**	4.5	3.75
51	Fab-labs and low-cost prototyping resources	9**	4.75	4.75
52	Smart phones as laboratory resources	7.75	2.25	4.75
53	Virtual labs and online learning resources	8*	3.5	4.5
54	Testing and lab facilities built by students themselves	9**	2.5	6
55	Student employment offices	7.75	6.25	5.5
56	International exchange offices	8.25*	6.25	6.25
57	Public funding	8.5**	5.5	6.5
58	Private funding	9**	4	5.75
59	Donations and patronage	9**	2.25	5.75
60	Stipendia and awards	8.25*	5	5

Drivers of change linked to the environment and available resources.
(*** Outstanding impact; ** very relevant impact; * important impact).

patronage activities, are perceived as having great potential for the promotion of "Engineering Education for All", 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. Connection with the industrial environment, promotion of such environment and a progressive shift towards the use of new low-cost technologies for supporting educational innovation, which may also support industrial innovation, are also relevant issues to consider, as will be also discussed in the following Section.

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 common causes of different problems. The process has been previously applied by our team in the search for solutions linked to teaching-learning processes, project-based learning methodologies and collaborations between academia and industry [5–7]. 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 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.

The numbered drivers of change correspond to the notation from Table 1 and Table 2.

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 3. The list includes those drivers with an impact above 8/10 and with low maturity values, 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

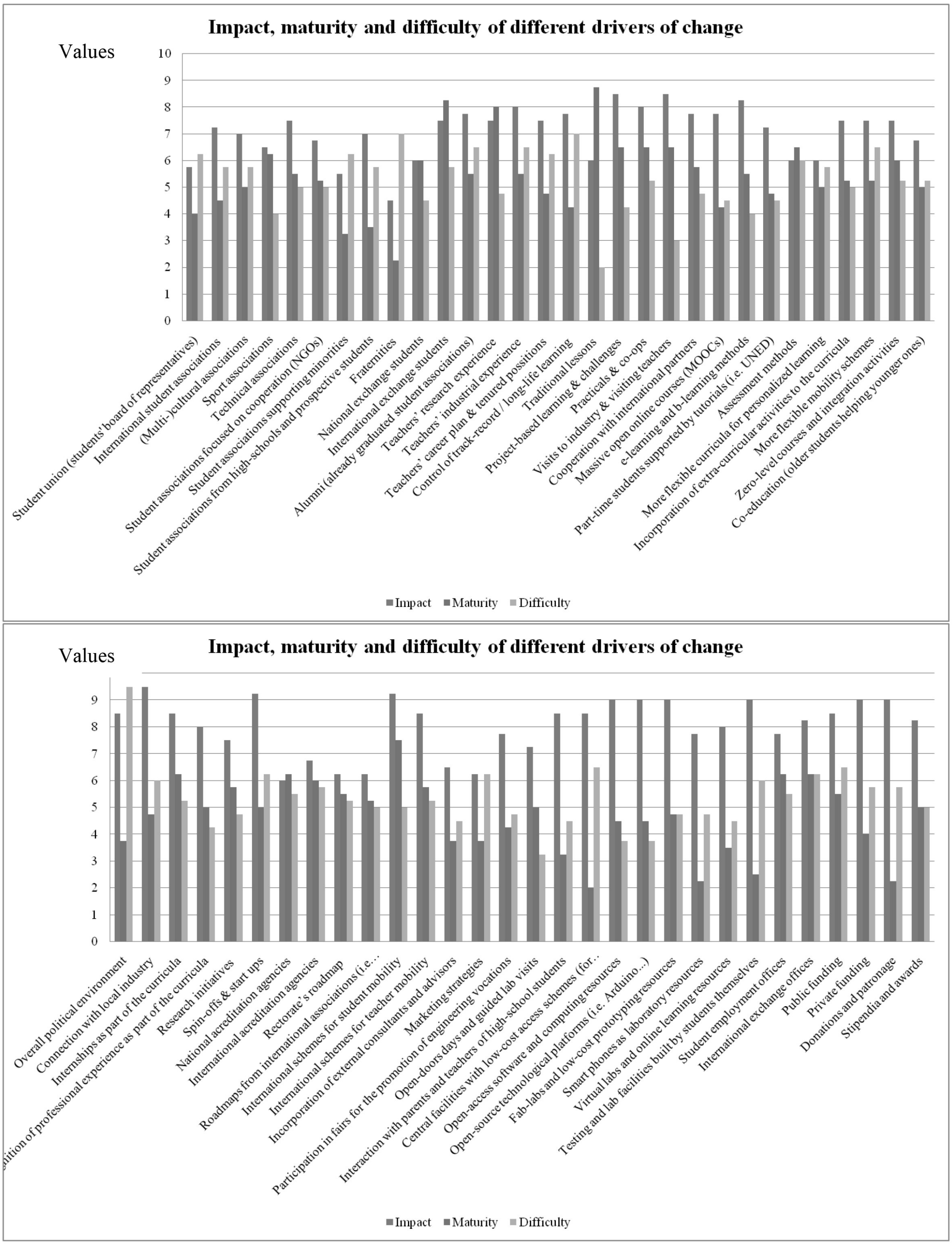

Fig. 2. Impact, maturity and difficulty of different drivers of change.

is beyond our current range of action), we integrate and highlight those 6 aspects we would like to study specially in depth with codes A to F.

Subsequently, we develop different cause-effect diagrams for the problems: "*the integrated driver of change "X" is not sufficiently mature*" (with X = A . . . F), so as to find the problematic causes and propose solutions in a more systematic way, after

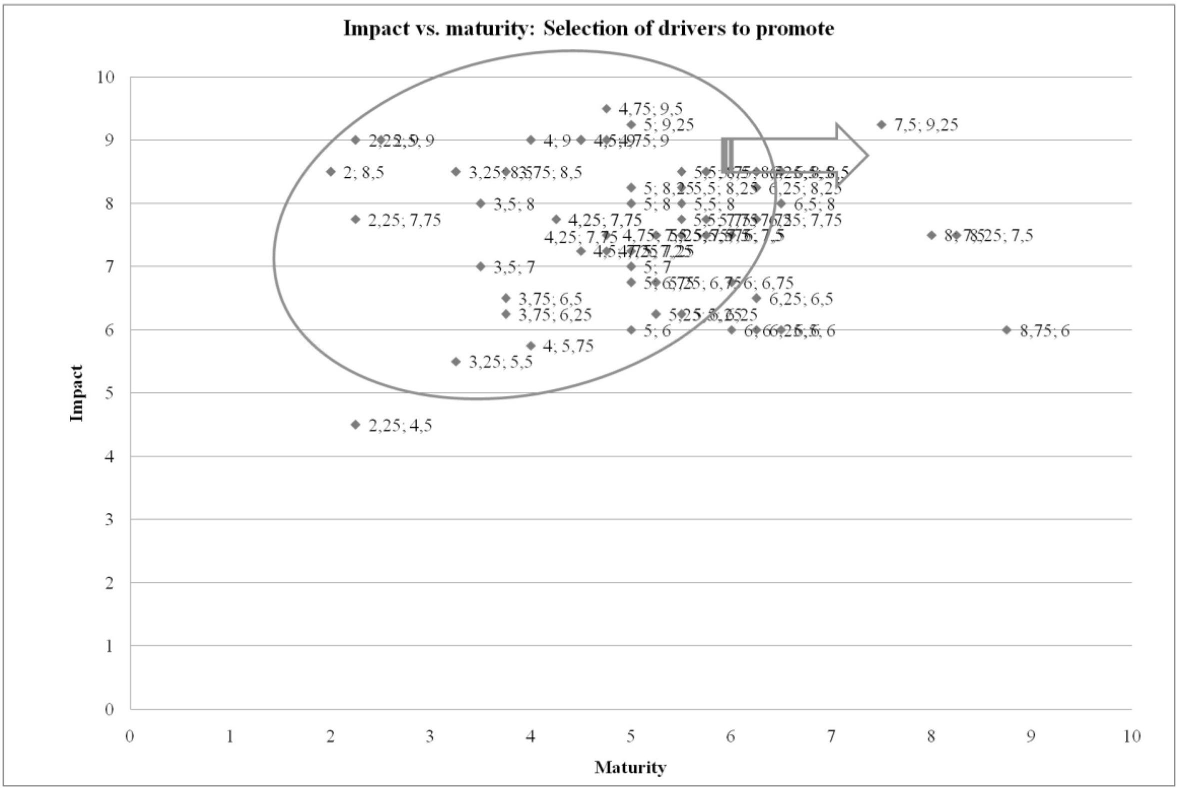

Fig. 3. Impact vs. maturity: Selection of drivers to promote.

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.

Main relevant challenges and areas of actuation include: improving the connection with local industry, approaching parents and school teachers to highlight the relevance of Higher Education and promote technological vocations, promote the use of central facilities with low-cost access scheme to optimize the use of technological resources, shift to open-access, open-source and low-cost technological resources as support for teaching innovation activities, involve students in the incorporation of new technological resource and increase the schemes for private funding and patronage activities, as compensation for the recent austerity policies, which at least in our country have importantly damaged public services, including Education and Healthcare.

The different cause-effect diagrams are depicted below in Figs. 4–9, 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 4, 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 more common in Europe, so several proposed solutions may be state-

Table 3. Detected relevant drivers of change needing special implementation efforts

Problem code	Agent to promote	Impact	Maturity
A	Connection with local industry	9.5	4.75
B	Interaction with parents and school teachers	8.5	3.25
C	Research facilities with low-cost access	8.5	2
D	Open-access software and computing resources	9	4.5
	Open-source technological platforms	9	4.5
E	Fab-labs and low-cost prototyping resources	9	4.75
	Virtual labs and online learning resources	8	3.5
	Testing and lab facilities built by students themselves	9	2.5
F	Private funding	9	4
	Donations and patronage	9	2.25

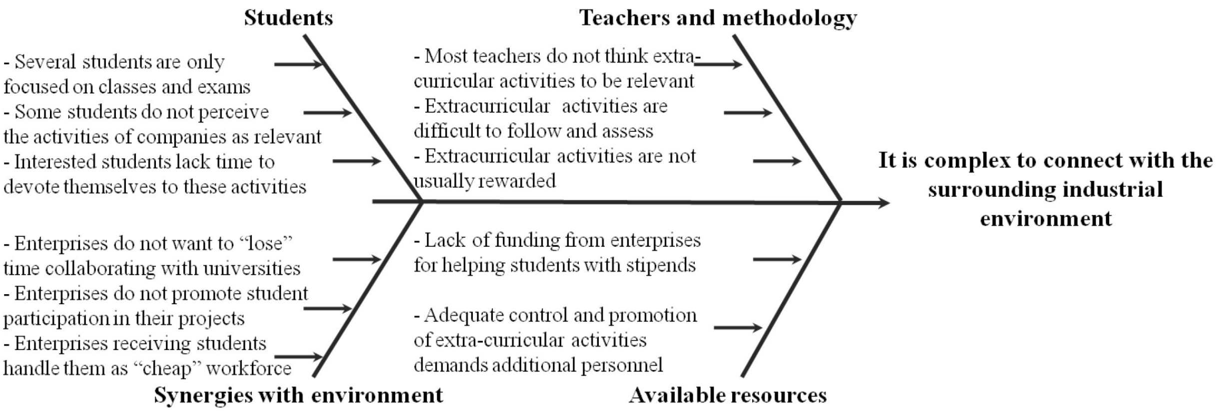

Fig. 4. Cause-effect diagram for the problem: "It is complex to connect with the industrial environment".

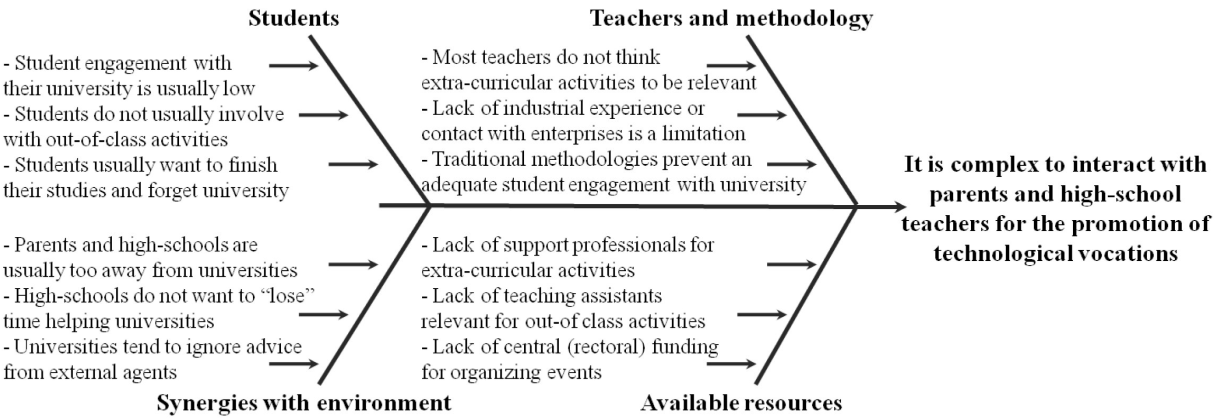

Fig. 5. Cause-effect diagram for the problem: "It is complex to interact with parents and high-school teachers for the promotion of technological vocations".

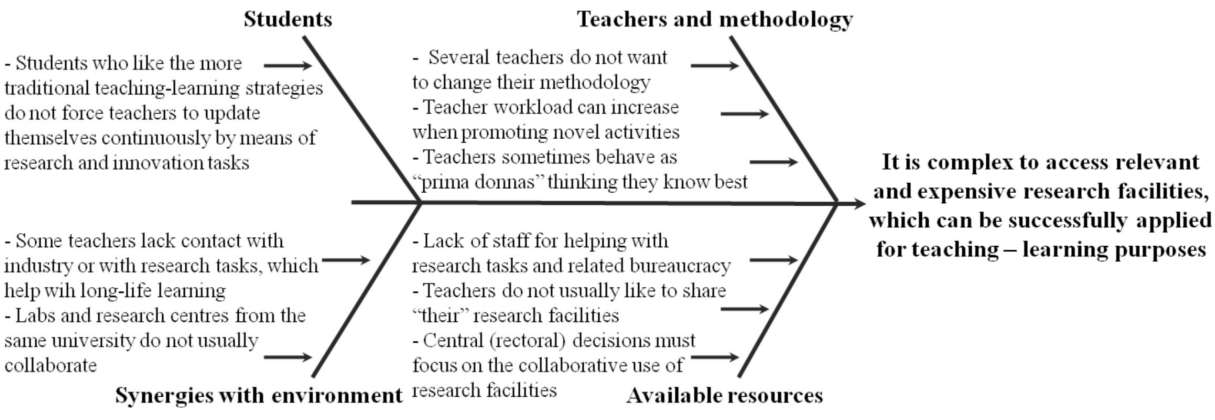

Fig. 6. Cause-effect diagram for the problem: "It is complex to access relevant and expensive research facilities, which can be successfully applied for teaching—learning purposes".

of-the-art in other countries. In any case we hope that 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

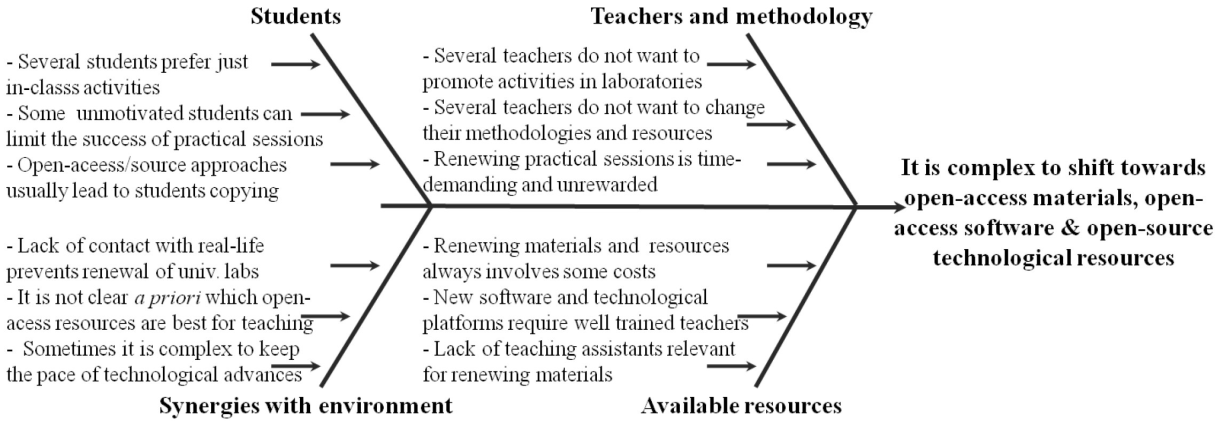

Fig. 7. Cause-effect diagram for the problem: "It is complex to shift towards open-access materials, open-access software & open-source technological resources".

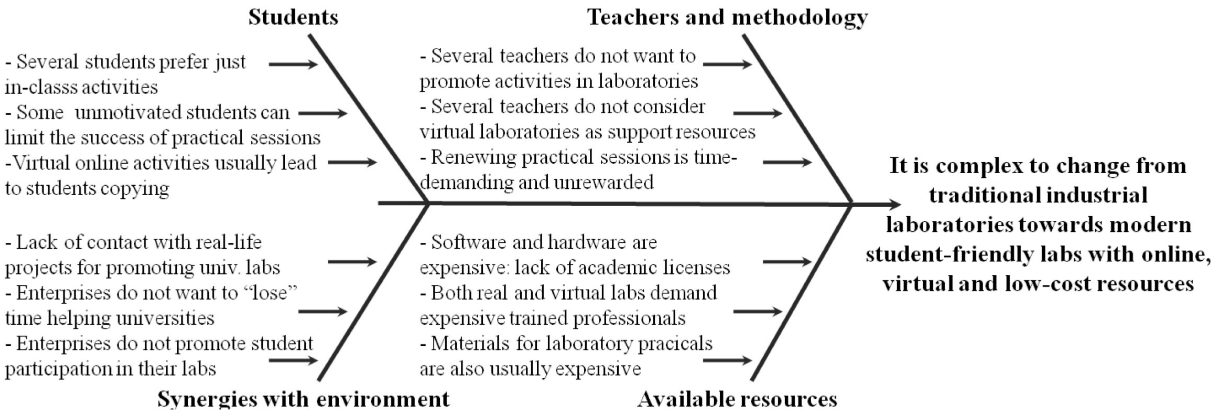

Fig. 8. Cause-effect diagram for the problem: "It is complex to change from traditional industrial laboratories towards modern student-friendly labs with online, virtual and low-cost resources".

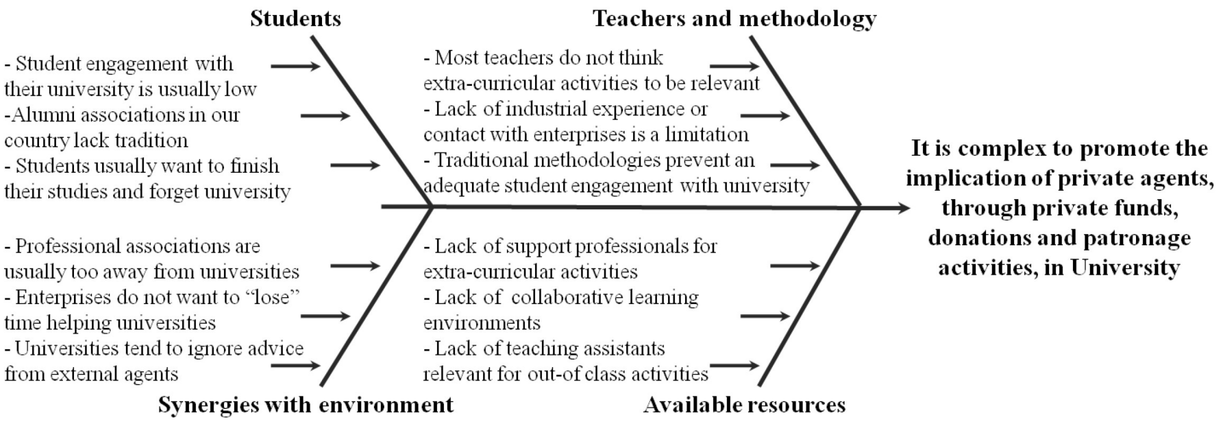

Fig. 9. Cause-effect diagram for the problem: "It is difficult to promote the implication of private agents, through private funds, donations and patronage activities, in University".

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 credit recognition and almost without academic fees, 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

Table 4. Table summarizing the main difficulties and problems detected for the promotion of "Engineering Education for All" 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.
	Include the possibility of carrying out stays in enterprises as part of the curriculum with adequate assessment.	Number of stays in enterprises carried out.
	Limit the number of intermediate assessment trials.	Number of exams per term.
Low engagement with University.	Improve the relationships between teachers and students.	Number of joint activities carried out.
	Involve students in departmental research, development and innovation projects from the beginning.	Number of stipends 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.
High-schools and parents are far from universities.	Include opinions and proposals from high-schools and parents when developing novel plans of study.	Advisory board meetings.
	Promote collaboration between high-schools and universities, invite school students to hands-on activities.	Number of activities carried out together.
Available resources:		
University labs do not share "their" resources.	The Rectorate for research focuses on (if needed forces) the implementation of a central technological hub with a low-cost open access for researchers and students.	Number of projects supported.
	Promote collaboration between researchers from different departments by means of specific calls.	Number of projects performed.
Lack of stipends and resources for 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.
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 and objective resource management.	Improved performance, surveys and questionnaires.

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, as well as "Engineering Education for All".

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. The overall "learning results vs. costs" ratio will for sure be improved, thanks to the incorporation of young, modern, well-trained, flexible and in fact not so expensive professionals. 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 second place.

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 [21]. 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 [22, 23]; on the other side, heavy subsidization of higher education may be carried out at the expense of primary schooling, which is unacceptable [21]. In fact, professionals of education, from Primary and Secondary, to Higher Education, should collaborate more intimately towards a more personalized management of students and their vocations, for instance by means of technological fairs, short-term stays of school students in universities and *vice versa*, among other options. Clearly, these austerity policies have importantly damaged the public services, mainly Education and Healthcare, during the last years throughout Europe, with the excuses of a yet unsolved crisis and with nasty effects still unassessed (*if you think education is expensive, try ignorance*). Fortunately, motivated and well-trained professionals serving these public services are setting the foundations for a better future. Accordingly, 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.

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 "Engineering Education for All", 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 aimed at personalized learning. The encouragement of a shared utilization of technological resources, although still having to cope with the traditional positions of "prima donna" professors jealous of "their" resources, will for sure bring new opportunities of collaboration and thus generate additional economical support from public and private funded research and innovation projects, which will in turn help to improve the whole teaching-learning process and to promote "Engineering Education for All".

5. Conclusions

In this study we have tried to methodically analyze the main strategies for the promotion of "Engineering Education for All", 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 an equitable access to Engineering Education and for helping the most talented and motivated students to develop their Engineering studies and, consequently, to devote their life to the Engineering profession, regardless of their social background and economical status.

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