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LIGHTS AND SHADOWS ON THE SY*STEM*

F. MARTÍNEZ-ABELLA[1], I. COLOMINAS[2], JUAN SANMARTÍN FERREIRO[3], MANUEL F. HERRADOR[4]

[1]ETSI Caminos, C. y P. – Universidade da Coruña
Campus de Elviña, s/n, 15192, A Coruña, Spain
fmartinez@udc.es – http://www.gcons.udc.es/
[2]ETSI Caminos, C. y P. – Universidade da Coruña
Campus de Elviña, s/n, 15192, A Coruña, Spain
icolominas@udc.es – http://caminos.udc.es
[3]OVISA
San Martín de Guillar - 27154 Outeiro de Rei, Lugo
juan.sanmartin@ovisa.es – http://www.ovisa.es/
[4]ETSI Caminos, C. y P. – Universidade da Coruña
Campus de Elviña, s/n, 15192, A Coruña, Spain
mherrador@udc.es – http://www.gcons.udc.es/

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Abstract. “Change is hard […]. But it’s worth it – and it’s working”. Thus ended Barack Obama’s section on education in the 2014 State of the Union address, after asserting that high school teachers from a number of states were making great progress when preparing their students for the new capabilities required by the new economy: problem solving, critical thinking, science, technology, engineering and mathematics. His words were followed by an announcement of a 2.9 billion USD investment for 2015 (a 3.7 % increase compared to 2014) in programs devoted to encourage training in the fields of science, technology, engineering and mathematics (summarized in the acronym STEM). The goal for the upcoming decade is to prepare 100,000 excellent teachers to obtain 1 million STEM graduations. What kind of problem has brought the first world economy to promote this initiative?

Every 20 or 30 years, matching successive revolutions or technological waves, societies in the most developed countries receive alarming messages about the risk posed by the available engineering pool not being able to satisfy demands by industry and research. After the recent wave, where digital networks, TIC and biotech have played leading roles, a new one is being announced associated to sustainable engineering, nanotechnology, renewable energies, fight against inequality, and biomimetism; its peak will be reached in the 2020 to 2025 period. Consequently, once again the alarm is ringing about the need to count upon enough engineers or STEM graduates in general to answer to the new challenge. This is why numerous reports commissioned by different governments and prestigious institutions have appeared, and all of them concur in forecasting a strong increase in the engineering demand for the upcoming years. Nevertheless, secondary education students’ vocations in most developed country drift away from engineering degrees, slowly but firmly. This observation, valid also in Spain, calls for a careful analysis and constitutes the essence of this paper.

1 INTRODUCTION

A few months ago, a nationwide radio program analysed the issue of the migration of young Spanish graduates to other countries. A young aeronautical engineer who was on the brink to travel to Germany to find the job he was not able to find in Spain spoke up. Just as him, he said, half of his class was packing to leave. The deep crises which we are hopefully leaving behind is the most visible cause among those which justify the noticeable drop in demand in engineering degrees in Spain, easily perceived, since many of them do not reach full occupation and in most of them the minimum admission grade has plummeted – in many cases, down to 5.5 over 10 (the minimum passing grade achievable). The number of bachelor degree students in Engineering and Architecture has dropped by approximately 26 % since 2008 [1], especially during the past five or six years, with a displacement in demand towards the field of Health Sciences. This situation, together with the tightening of the economic situation of most public universities after years of budgetary cuts and burdensome debt, brings with it the threat of structural reforms in centres which otherwise perform remarkably in scientific research and technology transfer. We can only hope, if the long-awaited economic recovery is as close as we would like, that this situation will correct itself little by little.

Blaming the economic crises for the decrease in interest for STEM degrees (some scientific disciplines other than engineering are also suffering a drop in demand) would be too easy, but it is not the full answer. In countries where crisis effects have not produced so much damage in the field of engineering a similar trend is also perceived: in the USA, Germany, Japan, the UK, Canada, Australia, Russia, Austria, Poland, Latvia or Estonia – all of them with an average GNP growth over the past few years of 2 % or higher – young high school graduates are not attracted toward engineering studies either, in spite of good wage expectations and a demand for engineers which in some cases has to be fulfilled by foreign hires (from countries such as Spain). The 2008 Eurobarometer, which was elaborated before the beginning of the crises, and various studies [2,3,4] show that in developed countries less than 2.5 % of young university prospects had an actual interest to study engineering – which in the case of women decreased to 15 %. The same studies show, however, that engineering is the majority preference of youths in developing countries (India, Malaysia, Brazil, Philippines… plus the Chinese giant), with a similar degree of acceptance among women and men. Which begs the question… what is the matter then?

2 PERCEPTION OF ENGINEERING STUDIES

Undoubtedly the economic cycle and short-term job expectations are decisive when choosing a professional orientation, though we often forget that actual professional performance will not take place until at least four years after first signing up for college (adding up to five or six if a Master’s degree is pursued); at that point, both the economic situation and the foreseeable future might have changed radically. To put it in another way, part of the engineering vocations follow trends approximately parallel to GNP growth. But many surveys carried out in Spain, Europe, Australia and the USA agree, showing that these factors are not the least important nor decisive when choosing a career. The image of engineering has progressively changed, paradoxically, opposite to the change engineering has brought about to society. Quoting the German sociologist Kogon in 1971, “engineers are the camels on which businessmen and politicians ride” [5]. This is a way to interpret the social perception that an image of a triumphant, socially worshipped engineer, capable of undertaking transforming project, was being progressively demystified. This image might still persist in some developing countries.

A survey included in the 2009 barometer youth on science and engineering (German Academy of Science and Engineering) [6] covering thousands of German youths tried to establish which profiles and qualities were associated to an ideal job as opposed to those which, in their opinion, were characteristic of the different engineering careers. This survey shows small differences between both images in relation to traits such as practical utility, general wellness associated to job performance, social respect or the chance to acquire new competences. The gap is wider when looking at application of your own talent and work autonomy, where engineering falls behind the ideal job, or new developments, where engineering stands out. It opens even wider when wage expectations, networking or work-and-life balance are considered, three factors in which engineering is perceived at a much lower degree than an ideal job in the interviewees sight. But the issues with greatest perceived difference are those related to job security, perspective of a full career and activity diversification, where the image of engineering is clearly below the ideal job. The authors, as active engineers, were surprised to read some of these conclusions, especially when considering the overlap with the successful attraction shown by careers in health sciences, which were even worse graded in the aspects where engineering was deemed most apart from an ideal job.

Technology has a positive image among the younger population, though this does not imply a vocational interest. It is also associated to icons who have been the protagonists of the most recent technological revolution, that of the digital era, at the reach of millions of young persons as mere users. To sum up, digital technology is accessible and opaque at the same time, even in middle and high schools, where it is considered a simple tool, a means rather than an end. Also, overexposition to social media (dozens of digital television channels, journals and magazines from all over the world on the internet, social networks, messaging platforms, blogging…) easily creates stereotypes about success which influence youngsters’ attitudes, including those who nowadays are applying to college. Very few engineers are visible regarding their social projection and economic splendour, being the traits that best define success in society today, and when they are, it is frequently due to activities not directly related to engineering. Professor Marjoram, from Aalborg University and member of UNESCO, goes so far as to assert that in developed countries the image of an engineer is that of a “geek” [7], and especially, boring, as caricaturised by Scott Adams’s “Dilbert” character. In this context, the general perception is that engineering is not “cool”. The Institution of Civil Engineers (ICE, UK) has accepted the challenge associated to this situation and has recently published a video piece attached to a promotional campaign of civil engineering among high school students – a campaign backed by numerous and relevant companies in our sector. The message is simple and breaking: engineers are happy while practising engineering, designing and building extraordinary infrastructures for society [8].

Another question to consider among the influencing factors when choosing a career is the extended perception of difficulty associated to STEM disciplines. Generally, one can posit that engineering (or rather, the attitudes that define engineering) is far away, when existent, from middle and high school classrooms. Physics, Chemistry and Math are dark and elusive when presented as a mere set of rules, which also has something to do with the decrease in interest in engineering.

3 SITUATION IN SPAIN

Aggravated by the crisis, the situation in Spain mostly shares the traits hereby presented. It is even more complex when adding to it the recent transformation of the regulatory frame of higher education which has turned the old short-cycle (3 years) and long-cycle (5 or 6 years) programs into 4-year Bachelor's degrees and 1- or 2-year Master's. Most engineering studies (technical and superior in the old denomination), easily identified and almost completely linked to regulated professional competences, have been replaced today by a variety of degrees with titles which identify their contents poorly and even worse their associated professional competences. Indeed, a few months ago around 300 000 students who met the requirements to sign up for college did so in one of about 3 100 verified Bachelor's degrees available in Spain nowadays, taught in 345 campuses or sites in 82 universities, about 60 % of which are public. 35 000 graduates were dispersed over 4 700 verified Master's programs, 20 % of which are taught in private universities [1]. Among Bachelor's degrees, around 650 correspond to disciplines in the area of engineering, architecture and construction, hosting about 20 % of first-year students. Looking at the offer in public universities, 6 000 different official degrees may certainly seem too many. There will be even more if the reform allowing for 3-year Bachelor's degrees, cautiously delayed by a pact between university presidents, is finally adopted.

It can be presumed that taking an educated choice in such a wide offer would entail gathering and processing a vast and probably unreachable amount of relevant information, even though boundary conditions such as geographic location or family economy have great weight. The scholarship policy, with a tendency towards more rigorous requisites, and the increase in university fees (the price of a Bachelor's degree varies between 12 € and 40 € per ECTS credit, and Master's degree between 31 € and 65 € per credit for first-time enrollment) frame in a different way the situation in each autonomous community, but vocation has usually played a primordial role when choosing any engineering degree.

Several externalities have already been presented, but the factors that depend essentially on the universities and engineering schools themselves cannot be avoided. The design of study plans and teaching, learning and evaluation methodologies have repercussions on pre-college students' eagerness, particularly because of their incidence on the academic success index, on the average real number of years it takes to finish a degree and on how the productive sector values the graduate employees they hire. It is often put forward, not without reason, that the first encounter of novel students with the most theoretical and scientific disciplines (which constitute the base of technological studies, displaced towards the later years) abates the expectations of what engineering activity should be at the time of their first enrollment. The difficulty to overcome those classes must indeed be related to the students' baggage in STEM fields and to the decrease in cut-off grades which has taken place over the last few years, and which in turn influences the dropout rate in the degrees in question. There are yet no statistically relevant data about this issue, since the implementation of the new degrees is still somewhat recent, and even less concerning the valuation that market forces will pose on the competences acquired by the new graduates. Engineers formed under already extinct plans in Spain were in general highly valued, though this did not hinder criticisms, shared by most European engineering schools, about the limitations in practical contents and the capacity to apply theoretical knowledge. This is an old debate, and though its dialectics are easy to present, the design of an effective solution is not as simple. Quoting Charles Riborg Mann's *A Study of Engineering Education*, prepared for the Joint Committee on Engineering Education of the National Engineering Societies, "Now evidences are multiplying to show that the time has come for a clearer definition of the relations among research, instruction, engineering practice, and industrial production. How to coordinate these elements most effectively is a large and pressing problem". These words were coined almost 100 years ago [9].

4 STRATEGIES TOWARD STEM REINFORCEMENT

We have presented up to this point a complex lattice of motives that in their whole try to provide an answer to the slow and steady loss of scientific and engineering vocations. The USA initiative destined towards STEM strengthening has not been the only one, though probably the one with the largest funding. Already in 2004 the National Science Foundation had pointed out that, if the trend identified in 2004 were to stay steady, three things would happen [10]: (1) the number of jobs in the USA which require science and engineering knowledge would increase; (2) the number of Americans qualified to occupy those jobs would at best stay the same; and (3) the availability of qualified people from foreign countries would decrease due to immigration restrictions for national security reasons and the intense international competition over people with such qualifications. In 2012, the same institution reported that the number of employees in science and engineering sectors showed a steady increase for almost 60 years. Indeed, out of a 182 000-person workforce in 1950, it had climbed up to 5.4 million in 2009, which represents a yearly increase of 5.9 %, much larger than 1.2 %, which is the rate of increase of the over-18 workforce as a whole. Nevertheless, between 2000 and 2009 the growth in number of STEM workers dropped to a 1.4 % annually, much lower than in the preceding decades. 2004 predictions were thus corroborating, which gave birth to the funding line.

In Europe, the alarms went off few years ago, supported by the three axis of the *Europe 2020* strategy: smart, sustainable, cohesive growth. Reports and projects analyzing the situation and proposing lines of actions appear everywhere. Already in 2000, the European Commission turned STEM areas into strategic when creating the European Research Space, which until the Barcelona 2002 summit did not count with a working schedule. Nonetheless, this schedule established a line dedicated to STEM study reinforcement, quantified through the increase of GNP dedicated to research, from 1.9 % to 3 % [11]. This increase would supposedly have a repercussion in the form of a demand of up to 15 % new graduates. Later on, in 2004, the European Commission published an exhaustive report about the need to increase human resources in science and technology [12], dependent on a young population that did not see a promising future in these areas. In the form of 27 conclusions, the reporting workgroup stressed various lines of work. We will quote them here because they synthetize, without getting into too many details, the main strokes of the most ambitious programs that have faced the same issue:

- Creation of a human resources policy for the European Union.
- Promote new knowledge-based companies.
- Gender balance in STEM.
- Wage increase in STEM jobs as a means to retain graduates.

- Increase of external talent attraction while ensuring a majority of UE nationals in STEM.
- Improvement and promotion of academic careers, starting from Secondary school, in the different STEM areas, by increasing funding, private sector backing and teacher formation.
- Promotion of science and technology across society through museums, exhibits, mass media, etc., and popularizing role models of both men and women representative of careers linked to STEM disciplines.
- Boosting of the popularization capacity of STEM graduates, frequently non-existent.

The European Engineering Report, prepared by the Institute of German Business and the Association of German Engineers [13], showed in 2009 revealing data about the percentage of engineering graduates in the EU, which on average constituted 11.9 % of the graduate total (14.5 % in Spain) with extreme values in Finland, 20 %, and Cyprus, 3.7 %. The report remarks "Engineers' contribution to technological innovation applied in the market place is indispensable for achieving higher economic growth as well as for creating new jobs, securing clean energy supply, sustaining natural resources and tackling the challenges associated with climate change. Thus, they will play an important role in putting into practice all three priorities set out in the Europe 2020 Strategy."

Other national, European and worldwide institutions perceive the situation in a similar manner. Scientific and engineering organizations have prepared concurrent reports: the European Council of Civil Engineers [14], the British Royal Academy of Engineering [15], the Spanish Transforma Talento [16] and FECYT [17] foundations, the International Federation in Engineering Education (IFEES) [18], the International Council of Academies of Engineering and Technological Sciences [19], the European Association of Engineering Education (SEFI) [20], the world education CDIO (*Conceive, Design, Implement, Operate*) initiative [21]… The number of documents that share the idea of boosting science and engineering as the engines of future development and under the threat of the lack of prepared, young people can be counted by the dozens. As it often happens, unfortunately, many of these studies cover the basics but very few actually develop and implement definite strategies. "Engineering education must reflect the interaction of engineers in industry and academia; universities must forge cooperative alliances with industry and national laboratories to promote the value of an engineering education". This statement, hard to argue with, comes up in the CAETS 2013 report [19] and in many others with similar but different words. Very few actually point out who is to take on this task and how to do it, setting specific lines of work and specifying how to fund them.

From a larger perspective, the OECD and UNESCO have also joined this transcendental debate. In 2008, OECD published the well-known report *Encouraging Student Interest in Science and Technology Studies* [22]. Besides gathering already analyzed questions on diagnostics and treatment, this report brings forth evidence-based foundations about the perception of engineering among boys, girls and general society, with a clear conclusion: if women accessed STEM studies in the same proportion as men, the lack of resources we are foreseeing for the next decade would stop being a problem. This fuels a profound debate on the role/gender binomial, in which both society and the media that has become its reflection play an important role. UNESCO, in 2010, published a report on engineering in collaboration with the World Federation of Engineering Organizations, the International Federation of Consulting

Engineers (FIDIC) and CAETS [23], offering a wide perspective on the evolution of engineering and its role in world development. The data collected in this report are overwhelming: 2.6 billion people in the world lack drinkable water; 2.3 billion have no sanitation infrastructure; 1.6 billion have no electricity service and 1 billion live in slums. Consequently, almost 1.5 billion people have a life expectancy of slightly more than 50 years, so engineering in general and civil engineering in particular have to be strongly promoted, since they will be the protagonists of the sixth wave of technological development according to Kondratiev's model [24].

5 LINES OF WORK IN STEM REINFORCEMENT

Various initiatives funded by different EU programs have tried to bring forth concrete ideas and solutions. The ATTRACT Project final 2012 report [25] details some general lines of Perception, Attraction and Retention, a worthy synthesis of the lines already detailed in the 2004 EU document [12]. The STIMULA project [26], also funded by the EU, which included the participation of the Universidad de Zaragoza, focused its work towards 14-year old students, with whom they worked for three years having them take part in different stimulus and orientation actions towards science and engineering. Their vision of STEM areas at the ages of 15 and 17, according to surveys taken after their activities, seem to reflect that the ages corresponding to Secondary school are the key moment at which they almost irreversibly opt for a vocational choice, that is, acceptance or rejection of STEM careers. In this choice, mass media, parents and school tutors have notable influence.

Other proposals have been developed in different countries to promote STEM areas. In Japan, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) is working since 2002 [22]. In the Netherlands, the Platform Bèta Techniek [27] links industry to high schools, and especially promotes the participation of girls, as does the francophone Les Petits Débrouillards [28]. The Swedish SciTech approaches science and engineering to society in a similar way as the German Sinus and Sinus Transfer [29], or the Belgian *Chip, Chip, Chip, Hurray!*, which uses interactive experimental boxes, and *The Great sExperiment,* which aims to break the gender barrier in STEM areas [22].

Among these various activities the ones organized in the USA and UK are the most salient. In the USA, the National Academy of Engineering, with the collaboration of powerful engineering companies, developed a website to boost the visibility of engineering under the motto *Changing The Conversation* (CTC) [30]. It includes an extensive activity program, including downloadable posters and stickers with the key messages it wishes to transmit ("Engineers help design the future", or "Engineering is essential to our health, our happiness and our safety", and even "Engineers make a different world"), besides keeping an active role in social networks. In a parallel effort, a number of executives in big companies instituted the *Change The Equation* (CTeq) foundation [31], with a similar objective and an even wider range of activities. Their website included very useful material to approach Secondary schools (presentations, experiments, multimedia…); it also explained hundreds of projects to bring science and engineering closer to all kinds of audiences, while infiltrating themselves in Facebook, Twitter and YouTube to spread their messages.

British initiatives have been led by the Royal Academy of Engineering, the Institution of Engineering and Technology (IET), the business lobby CBI, the ICE or the EngineeringUK

Foundation, whose patrons are the most relevant companies and scientific or engineering organizations in the UK. In all cases, one can see similar approaches as the ones from the USA: simple and clear messages about the impact of engineering, popularization of all sorts of engineering activities and basic orientation towards Secondary school students, their parents and their teachers. For instance, the Tomorrow's Engineers program [32] reached 40 000 students from almost 1 100 schools all over the country. This seed has provided fruit, since from 2015 the statistics show a slight recuperation (or at least, the end of the decline) of the interest in engineering university degrees.

6 CONCLUSION: THE SPANISH CASE

So, what about Spain? The concern about the excess or lack of STEM graduates in the future has stayed in a secondary plane to the evolution of the economic crises, which has damaged the latest engineers to enter the workforce. Various national foundations develop directly or indirectly STEM discipline diffusion programs, among which we can point out FECYT, together with museums such as the National Museum of Science and Technology (*Museo Nacional de Ciencia y Tecnología,* MUNCYT) or the MC2 (Museos Científicos Coruñeses) network, but we still lack a national initiative which groups the individual actions that are undertaken with great effort and variable efficacy. Universities and their engineering schools have perceived the important decline in enrollment and the minimum cut-off grade of their new recruits, so they are probably the institutions that have first reacted to the mid- to long-term problem we can foresee. We have devised outreach programs for high schools, which, though positive, may fall among youths whose personal projects fall far from STEM disciplines since the mid school level. Very few of these activities are launched adding up efforts, and even less with a focus on 11- to 14-year olds. The Spanish university structure, organized by the autonomous communities, brings with it a few virtues to the system but renders difficult to engage in joint ventures, in spite of the existence of the Conference of Presidents of Spanish Universities (*Conferencia de Rectores de Universidades Españolas*, CRUE), that really attack the root of the problem. The Civil Engineering School of the Universidade da Coruña (*Escuela Técnica Superior de Enxeñaría de Camiños, Canais e Portos*) launched in 2013 an intervention program with a multi-pronged approach, taking advantage of synergies with MUNCYT and MC2 [33].

Because, the problem exists. The direct relation between investment in STEM education and research and national growth is proven, and future development solely based on the import of foreign talent is inconceivable. This is the reason that has alarmed societies such as the German, British or American, and state institutions, national organizations and associations, universities and, of course, businesses, have committed themselves to the task of putting out this fire.

The problem our society faces is not, in any case, the size of schools with less students than ten years ago. To destroy is easier than to build, even if it means blowing up a system that – though not without flaws – has given Spain a prosperity unknown in the previous decades. The real problem is that our nation is gambling with being or not in the first ranks of knowledge, with counting with a large enough cohort of young people ready to produce engineering here or anywhere in the world and with breaking the eternal imbalance between men and women in STEM disciplines. A spearheading national program is needed, led by public and private institutions, that can program activities, support teachers in all stages of education and repair the weak image portrayed by science and engineering in society today. We need to engineer how to revive engineering.

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