The role of hard and soft skills on engineering education

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***Abstract* – Technological competences alone are not enough in the present world. Society needs responsible leaders and entrepreneurs. PUKHA (To Project, to Undertake, to Know How to Achieve) is a recent framework launched at Faculdade de Engenharia da Universidade do Porto to foster the so called soft skills on its students. Over 300 students have been enrolled in 40 different projects for the last 3 years. Through hands-on projects, students from different academic years work together in students led teams aimed to achieve something with real value. They have the opportunity to develop and improve their responsibility, communication, leadership, management and entrepreneurship, among other skills. That leads to a process of education and innovation on engineering, outside the classroom. Based on first results, these projects play a key role on the students learning process, as they are more motivated to enrich their knowledge and experience towards a successful future as engineers. As leaders, students develop management skills from financial and project planning issues to emotional and motivational fields. As potential entrepreneurs, they have to accomplish their initiatives (some projects may even lead to start-ups). The freedom students enjoy in those projects and their own leading role creates the atmosphere where innovation skills can be developed and innovation may take place. The hurdles faced by the leaders will also be presented. PUKHA develops the ability to work on flexible and changing teams. These skills are most important for leaders to influence and inspire the work of others. This paper addresses the main factors on which student's initiative, responsibility and effective leadership are built upon and tries to draw a set of useful guidelines to the university education of young people.**

Index Terms - hard skills, soft skills, engineering education, students' leadership, project-based learning.

INTRODUCTION

Today's vulnerabilities induce a re-examination of the role of engineers in society. Clearly, engineering must go beyond pure technology, based on a solid scientific and technological knowledge. Firstly, society needs responsible leaders and entrepreneurs. Secondly, the ability to work currently on flexible and always-changing teams became a critical job requirement, as well as the capability to see interconnection between a broad range of activities that makes them leaders through their ability to influence and inspire the work of others (see, e.g., [8]). Finally, the proficiency at learning how to learn is vital to lifelong learning [6].

Consequently, the use of active learning tools is grabbing the attention of the pedagogical community as an answer to the recent education process requirements for this century. The most important condition for learning is the interest of the learner. It is well known that students are more motivated (and, consequently, learn more) when they are actively, rather than passively, involved in the learning process.

Lecturers are being prepared to face this new reality [5],[9]. Several frameworks have been launched to develop the so-called process skills and competences. For instance, project-based learning (PBL) focuses on team-based activity relating to learning and to solving large-scale complex open-ended problems [7]. Different implementation approaches of this framework have been applied, such as: an integral part of a 4-year undergraduate engineering degree programme attempting to reach a balance between hard and soft course contents [1], a combination of academic and commercial learning into a modified teaching approach [2], a mixed project based learning framework to investigate competencies that students should acquire to prepare their future as engineers [3] and a development of knowledge landscapes by transforming and integrating existing and context-dependent knowledge [4].

A new framework named PUKHA (To Project, to Undertake, to Know How to Achieve) was launched at Faculdade de Engenharia da Universidade do Porto, Portugal, aimed to fulfil these needs by involving students in a hands-on experience. This framework is presented in the next section.

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The aim of this paper is to present the framework of this experience and to make a first evaluation of the results based on two case studies.

PUKHA FRAMEWORK

PUKHA projects are very different from the ones that traditionally students were used to follow and still do in the last year of their engineering courses. In fact, while in the traditional projects students only design but don't concretize their projects, in PUKHA the goal is to achieve the materialization of something with commercial value.

In mechanical engineering degree courses, at the Faculdade de Engenharia da Universidade do Porto (FEUP), traditional projects were undertaken individually or in groups of two students and were done within a semester or an academic year. PUKHA projects are always followed by teams, typically of eight elements, and they extend, in general, for two or more years. In each PUKHA project work together, necessarily, students in different years of the degree courses. As much as possible, PUKHA projects have to be multidisciplinary. Although the idea arose in DEMEGI (Department of Mechanical Engineering and Industrial Management), there were engaged from the beginning students and teachers of other departments. In addition, each PUKHA project has one or two students' leaders supervised. by two or more supervisors (despite no mandatory, typically professors of FEUP). We then explain the reasons why PUKHA projects have the above mentioned characteristics.

Nowadays it is clear that entrepreneurship is a skill that most engineers must have to perform well in a changing world, to give their own contribution on the improvement of human life conditions. Somebody who fears the concretization can hardly be entrepreneur. Besides, there is an enormous gap and difference, between design and concretization. While concretizing, students notice how good general ideas, despite being extremely important, are not enough. Details are also important for quality, production time consuming and costs of a product. Concretizing, students may learn how details can even determine the viability or not of a design. This means that not only entrepreneurship skills but also the quality of an engineer depends on this experience of concretizing his own designs. The feeling and skills developed in this exercise of concretization can shape the future of the new engineers.

It happens, also, that, 'to do' is the best way to learn. Confucius, a Chinese philosopher, had already this conscience when he said, in the 6th century BC:- "What I hear, I forget, what I see, I remind, what I make, I learn".

In PUKHA projects students have to use and integrate knowledge included in several courses of their graduations. To accomplish that, they could count with the help of the supervisors or of colleagues of the same or different courses, and also with other people. This integration of competences is very useful to deep their knowledge and to establish new links and relations with different branches of knowledge.

The fact that we consider concretization so important does not mean that the proponents of PUKHA projects at FEUP defend a teaching/learning pedagogy based only in project learning. On the contrary, they consider that engineers must be 'deep generalists'. This means that they must have a deep and consistent body of scientific knowledge, in several domains, not only in the traditional fields of mathematics and physics, but also in chemistry, life sciences and others. This broad body of scientific knowledge is crucial to work successfully in multidisciplinary teams, to solve complex problems as real problems usually are. Clearly, it is also crucial for life long learning. It happens that this deep and large spectrum knowledge can hardly be acquired without a well structured teaching of the basic sciences. PUKHA projects are very important to develop the soft skills that entrepreneurial and responsible engineers need. However, without a strong hard core of deep and general scientific knowledge, their performance should be very limited, especially in the long term.

The participation of students in different levels (scholar years) of their courses is a pre-condition of PUKHA pedagogy, for three reasons. First, one year is not enough to develop entrepreneurship skills. Students must start much before reaching their last degree or master degree year. Second, students have an enormous pedagogical capacity. They often learn easier with their older colleagues than with their teachers, and very often they learn it better and deeper when they teach or help younger students to learn. A school that despises this pedagogic resource wastes one of its best springs. Third, in such groups, students practice and develop their team work skills, eventually performing different tasks, with different responsibilities, in different years of their academic path.

Students' leadership, together with the freedom students enjoy in PUKHA projects is, obviously, a good opportunity to develop their will, to take risks and responsibilities, and so, to develop the skills a leader needs.

This is also an important factor in motivation. Motivation is the stronger lever for learning and to develop skills. Up to now the most evident result of PUKHA pedagogy in FEUP was that many students participating in these projects started working much more than before, not because any teacher demands or examinations 'forced' them to do so, but because they could work freely on their own projects and become responsible for its success or failure.

THREE YEARS OF PUKHA PROJECTS AT FEUP

PUKHA projects have been launched for the first time, as a pedagogical experiment, in September 2004. The goal was to launch 10 experimental projects and to have around 80 students working on them. The Faculty board of directors sponsored the initiative with € 25,000.

In fact, 14 project proposals have been announced to all the Faculty students and, in some cases, to students of other faculties and universities. Only one of those projects was proposed by students. All the others were proposed by teacher, having, in a small number of cases, companies interested and more or less engaged on it. Twelve of those projects had a number of interested students enough to start. Out of those 12 projects only one interrupted its activity and was not ongoing at the end of the academic year of 2004/05

because the first and the second leaders of the group meanwhile started working. In those 12 projects participated 68 students of mechanical engineering, 16 of management and industrial engineering, 6 of electrical and computing engineering and, finally, 5 students of the School of Music and Performing Arts of the Polytechnic Institute of Porto.

At the beginning several proponents and other professors considered that only students in the final years of their courses should be accepted to participate in those projects. The others were considered to be too young and without enough knowledge to have a positive role in the projects. B. Magalhães, one of the authors of this paper and the first proponent of PUKHA projects, refused to accept teams without students at all levels, in their courses, with the exception of the first scholar year due to the later start of the academic year for first year students. Among the 90 students of FEUP participating in those projects there were 20 students following the 5th year, 27 in the 4th, 22 in the 3rd, 21 in the 2nd and one in the 1st.

In September 2005, 11 out of 12 initial teams presented the results of their work to the faculty, in an open session and with posters stocked in the main corridor of FEUP. Most of the projects achieved the goals previewed for this first year experience. Some overcame the expectations, while only a small number did not achieve the expected results. Many students worked very hard in their projects, not only in working days but also in holidays and weekends.

Students' leadership functioned, in general, quite well. Generally, leaders were students of the last two years of their courses. Some of them had directly shown their interest in leading their groups. Others were chosen by the proponents or supervisors after interviews done to the older candidates to participate in each team. Once chosen, the leaders had a strong responsibility in the choice of the other members of the team. In fact, the first and one of the most difficult tasks of an entrepreneur is to choose a good team to work with. No responsibility could be demanded to the leaders if they were not free to choose their respective teams, not only among the candidates first presented, but also among other students, namely chosen directly by the leader.

The fact that students could work more freely than usually and take responsibilities they did not take before, improved their initiative. For instance, some of them launched the Astronautics, Aeronautics and Modeling Nucleus of FEUP. PUKHA enabled them to do things in their faculty, that before they had not the courage to do.

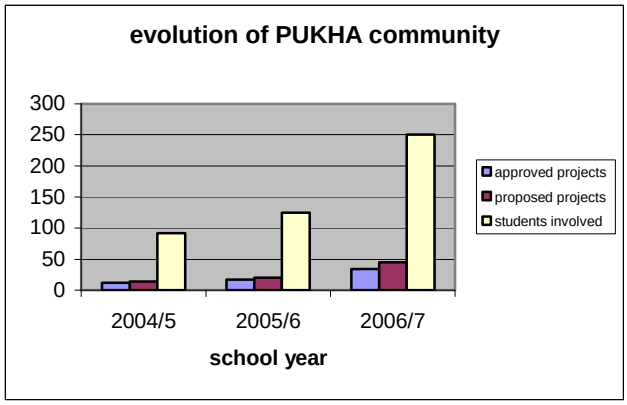
Moreover, the relationship between students and teachers improved, for those participating in PUKHA projects. The good results of the first experiment led the board of directors to continue supporting PUKHA experiment. But, due to financial difficulties, the board of directors maintained the same funding and recommended the coordinators of PUKHA experiment to maintain the total number of projects (ten, according to the first decision). Nevertheless, the interest of students and professors resulted in 17 projects approved for 2005/06 and 125 students involved. As a result, the amount of money available for each project was reduced. Getting additional funds or other kind of external support for their projects was also a new skill leaders had to foster.

A very important feature in this second year was the growing number of students and professors of other courses engaged in PUKHA projects and the participation, in several teams, of students of two or more different courses together.

In March 2006, a second public presentation of the projects took place and a TV educative program was produced. Once again the results were very positive, however with several projects delayed in relation to forecasts.

The financial situation of FEUP prevented its board of directors to increase the global amount of funds for PUKHA projects in 2006/07. The number of projects approved was 34 though, with over 250 students enrolled (see Graphic 1).

GRAPHIC 1
EVOLUTION OF PESC COMMUNITY



Although there are not yet results of the academic year of 2006/07 in course, we may already take some conclusions from the almost three years of experience:

- PUKHA projects got a growing interest of students and professors not only from DEMEGI but also in other departments of FEUP.
- For most of the students engaged, working in PUKHA projects has been an important factor to increase their motivation and interest in their courses.
- Even so, students would like and deserve to see their work in PUKHA projects recognized and compensated in their classifications, what does not always happen at present, due to the experimental statute of those projects.
- Students' leadership was a very good experience. There were only a very small number of exceptions in which the leaders did not perform well or were forced to abandon their tasks for professional or personal reasons. Naturally, each leader assumed his/her duties on his/her own way, according to each one profile and the team and work needs.
- The participation of students in different scholar years together was so positive that nowadays almost nobody questions the participation of younger students (excepting specific projects in which the knowledge of more advance matters is essential to the work)
- The multidisciplinarity of the projects increased, but it is still quite modest.

- The lack of installations and other working facilities, and the difficulties to find within the timetables of different scholar years and courses, compatible meeting hours, renders team work quite difficult.
- The participation of companies in the projects is still low.
- The participation of students of other universities and other countries is still low.
- Until now only one project is leading to the creation of a spin-off.

We may conclude that PUKHA projects, by increasing the interest of the students in their courses and demanding the integration of different matters to achieve results, are an excellent contribute not only for their soft skills development, but also for deepening and enlarging their knowledge and so, for improving students' hard skills too.

Looking to the future, we consider that PUKHA projects need to develop in the following directions:

- To become more interdisciplinary and engage students not only from the different integrated master degree courses of FEUP (that replace the older five years long graduation courses), but also from other faculties, other universities and polytechnic institutes.
- To become more international, engaging students, universities and other education and research institutes from other countries in common PUKHA projects (or similar ones).
- To engage a growing number of companies and other institutions.
- To get more private funds for both PUKHA framework and specific projects.
- Stimulate the launch of spin-offs when the ideas developed, the results achieved and the market needs do justify it.
- To become integral part of students' curricula (as minors, for instance) and, as such, to get time, installations and equipment available for them.
- Once included in the academic curricula of the new engineering master degree courses (after the end of the experimental period that lasts already for almost three years), students shall deserve an evaluation of their participation in PUKHA projects, to count to their final classification.

CASE 1 – IDEIA.M

IDEIA.M is the acronym of a project dedicated to the research and development of musical instruments made of composite materials. The team is composed, at this moment, by six students from mechanical engineering. Curiously, they all play musical instruments. They develop their work at FEUP and they have the support of INEGI (a technological institute) and of the School of Music and Performing Arts of the Polytechnic Institute of Porto (ESMAE).

Júlio Martins, the first author of this paper, is the leader of this project since its beginning (October 2004). This project is supervised by Torres Marques, who challenged the students to this issue and allowed students to feel comfortable to run the project. He trusted the team members and kept himself informed, always looking for opportunities to help them to pursuit and reach their goals.

It has been very important for Júlio to play this leadership role and to work in this area. It was definitely the perfect matching between mechanical engineering and music, his main interest and his hobby. Additionally, IDEIA.M enabled his return to school, in a sense that Júlio academic performance was far from brilliant.

Júlio says that "in this project, I felt as part of an engineering school, having an active intervention in my own learning process. Parallel to the lectures where we learn engineering basis, one of the main goals of this project is the development of other skills, vital to our success as future engineers. As the final result of the work, these skills may be more important than the engineering product, even considering the importance to reach a material goal. Every educational intervenient will gain with this new attitude. Students, of course, get better prepared, teachers get more and actualized information, school enriches itself by increasing its own reputation, and as a more global view, national governments and society take benefits because, with a very low investment, will have a new class of engineers ready to develop new ideas, new attitudes, and even new companies."

Julio is always trying to explore new experiences that may be important to the team members as students, persons and engineers. The team had to look for the knowledge needed to evolve the work. They contacted companies, teachers, researchers, other students and even shop floor workers. They invited companies to collaborate with them, and they have the honour of having renowned companies helping them. For instance, Alhambra Guitars (Spain) and Renner (Germany) provided musical instrument samples, L. R. Baggs (U.S.A.) provided electronic pickups, Corticeira Amorim (Portugal) or Titanium Industries (England) provided materials, Gramafam (Portugal) and DHL-Portugal provided services and CISM (Italy) provided a one week course and stay in Italy. They also made their own prototypes. They used state-of-the-art machinery and software. They prepared visits to companies (Alhambra Guitars) and travelled to other countries (Spain and Italy). They presented their work, and prepared events to these presentations, at FEUP, at schools, and even to investors, and they spoke in public and even to media: newspapers (Público, Primeiro de Janeiro,…), magazines (CAD Project,…), radios (RCP) and television (RTP). They developed team relationships and helped each other in the course and in the project. They learned to work in group, dealing with motivational and emotional factors.

Naturally, students faced some hurdles. These projects are developed simultaneously with classes with no pre-defined counterparts to help on motivation. Occasionally, students may have seen their efforts awarded with ECTS of courses. However, it is not a standard procedure. "This is one of the drawbacks, because I cannot demand bigger responsibility and more dedication from team members. With new and more visible mechanisms of motivation, relevant results will be achieved", Júlio highlights.

However, a new and positive attitude is one of the most important ideas he wants to pass to the other members. In his opinion, engineering will lead the world and this situation will be even more evident with the increasing need of innovation and entrepreneurship. And are not only important the leadership skills of the leader, but also the opposite view of the team members to develop the ability of being led and even in that position to have an innovative, entrepreneur and responsible attitude.

Currently, and because this is a team formed by undergraduate students, his role as IDEIA.M leader is reaching the end. However he felts his mission was fulfilled.

A business company that will continue this work is being created by three IDEIA.M members that are finishing their Mechanical Engineering courses. Another team member, following the fourth year, is also starting his own company in another engineering area. And the continuation of the school project is now being passed to younger students.

"We all agree that IDEIA.M, and the PUKHA framework, is a unique experience to show us that everything is possible and after this, it looks easier. IDEIA.M is the university that university itself can't be." says Rui Julião, other team member.

CASE 2 - STRAPLEX

What is it about?

STRAPLEX stands for STRAtospheric PLAtform EXperiment and offers the scientific community the possibility to send experiments into the stratosphere using balloons filled with Helium. Depending on the mass of the experiment, STRAPLEX can reach up to 40 km altitude. It consists of a capsule designed to transport navigation, communication and scientific equipment to the stratosphere and return it safely to the ground with the aid of a parachute.

How it was born

The project was born in 2005 under the name of STRATOSFEUP and was initially proposed by one of the students involved in the NRA, the amateur radio club, installed at the Electrical Engineering Department of FEUP.

After a period of consolidation of the initial idea, the project was presented to the Department of Electrical Engineering, which decided to finance it. It was also presented to the European Space Agency (ESA), which was very supportive from the very first moment. The name was then changed to STRAPLEX.

How it became PUKHA

Given the closeness to the philosophy of PUKHA projects, STRAPLEX submitted an application in order to became one of the PUKHA projects soon after it began, in the edition of 2005/2006. This allowed for more recognition of the project by the school, some extra funding and, above all, to reach more students potentially interested in collaborating in the project.

Who is involved?

After two years from the initial idea, about twenty people from FEUP have been enrolled in STRAPLEX. Most of them are students or former students. The core of the project consists of six persons, most of them students at the time they joined the project, although two of them have already graduated.

Organization

Since the beginning of STRAPLEX, people were organized by the different tasks involved. There was never a need for a strong leadership, as this group was always very proficient at organizing itself. Discussions have always involved the majority of the team, leading to strong decisions based on consensus. Moreover, a significant concern about the dissemination of the information among the team members has contributed to make the organization easier. Students and teachers have always worked together in equal terms. This project has included students as young as second undergraduate year. Therefore it is natural that the leadership has passed from hands to hands, and students have had a major role on this field.

Experience

From the student point-of-view, STRAPLEX have been an opportunity to apply the different fields of knowledge acquired during lectures. The organization skills are also explored and improved as well as the teamwork skills.

The opportunity of contacting people from other universities, with different cultures, different methods of organizing tasks and different methods of solving problems is also an important experience. In detail, students from The Netherlands and from Spain have already been involved in launch activities within STRAPLEX. Also, contact with ESA staff has been constant in this project. Another important point is the closer contact between students and teachers. Students learn much more from teachers when they have the opportunity to discuss specific problems and their solutions.

Teacher Point-of-view

For Sérgio Cunha, supervisor of STRAPLEX, the PUKHA framework makes just sense. Teaching engineering without field experience is not enough. One the other hand, students are keen on participating in research activities. Under PUKHA, these goals become possible. Furthermore, multidisciplinary and scientifically demanding projects like STRAPLEX generate the need to take the acquired know-how to the limit. Another interesting aspect is the fact that teachers, throughout their professional life, tend to specialize in certain fields and allow for knowledge in other fields to become out of date. Although not as deep, students have fresh knowledge in a majority of fields. So, in many situations during the project, students become the teachers and vice-versa.

A major challenge for PUKHA is the full recognition of this framework as part of the undergraduate course. Students need to have their effort directly recognized, in order for more of them to feel the appeal to participate.

CONCLUSIONS

The reason for the PUKHA projects resides on the vast pedagogical potential recognised on the students. Leadership of well established projects and knowledge transfer among students can help them consolidate their understanding of both engineering and soft skills.

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