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Two revolutions in the engineering settings, two paradigmatic learning experiences

José Figueiredo
CEG-IST, Instituto Superior Técnico, Universidade de Lisboa

ABSTRACT: Engineering practices evolved from prehistory, sometimes in a fast pace, other times in a slow pace, according to the gradient of environmental change. Engineering practices begun with mankind. Simplifying we can say that the evolution of engineering practices basically shows two revolutions. The first, many centuries ago, was commanded by the absorption of exact sciences in the way engineering is practiced, modelled, developed. The second, timidly in motion, is pulled by the absorption and internalization of social sciences. We believe that learning is driven by practice. Collaborative practices and group work with "local" autonomy are feasible supports for learning strategies, and should be explored in a wide range of different settings. Designing and internalizing a new education paradigm in engineering is urgent. Our research method combines qualitative narratives and abductive reasoning in cultural contexts of engineering practice, through history, exploring conjecture. The results point out to the lack of consensus on some concepts, definitions, and objectives, thus, based on reflective reasoning, some future directions are proposed in a pattern of conciliation. The novelty about this article is only the tentative internalization of new engineering practices, some of them already known, others less recognized, but all underrated.

KEYWORDS: Project based learning, Active Learning, collaborative learning, coopetition.

I. INTRODUCTION

Engineering is about practice, about doing, designing and developing systems and often using technological artefacts and tools. Engineering practices were born with the primitive man, creating instruments of war, hunting and sheltering. That phase of engineering practice was by far the longest one. After a certain time, man begun creating abstract models and symbolic reasoning and concepts taken from what we now call mathematics and physics. Although these concepts were born in antiquity they evolved, creating solid bodies of knowledge that we use to address as exact sciences. These concepts are available as instruments and support, and engineering practice begun to absorb them and use them to sustain practice. This is what we call the *first engineering revolution*. Examples of this revolution are the creations of the Babylon's, Egyptians, Greek and Romans [24], [21], but also all the kind of engineering produced till now, or at least till the last quarter of the twentieth century [34], (Rojtedr, 2004). From the last quarter of the twentieth century on, we have been influenced by what we call the *second engineering revolution*. In fact, engineering nowadays has to absorb and integrate concepts from the social sciences in order to respond at his best to the challenges of our modern life [50]. Our modern life has many surprising characteristics, mainly related to the increasing number of relations between things, volatility of contexts of work (both facts are indicators of a higher complexity) and also due to the fact that decision about what to do and how to do it tend to be displaced from an appointed leader to a team, from a stable plan to the emergence of action. In these emergences of action, we have distributed decision and all the chain of action results more complex.

These days we are used to live with plans in progress, a continually in motion draft. The plan is not rock solid, as it used to be. Complexity and the need for negotiating the course of action with stakeholders, as well as definition of requirements and other related details lead to the need of socializing, bargaining and negotiate [45], [44]) to develop new knowledge and understand the situational social relations and tensions that are always emerging. The engineer needs to understand the social, the complex socio-economic environment of engineering design and development. Knowledge is both situational and predictive, as it is cumulative and the main support for the ongoing and continual learning processes. So, there is a need to develop and endure social skills [36] in order to be able to practice in the desired way, in an effective manner, today and towards the future. Engineers, as actors in situated environments, in situated circumstances, need to develop a panoply of knowledge abilities, such as capacity to develop new knowledge, creativity, critical thinking, ability to work collaboratively, and resilience. All that should be "mounted" in very good technic skills, of course. This is what we point out to be prepared to participate in the *second engineering revolution*.

Engineering "in full" is our purpose, an engineering that exercises and explores all kind of different concepts, soft and hard, qualitative and quantitative, using deduction, induction and abduction, and able to create solutions in a universe in motion, using flexible decision structures, often distributed. We talk about an engineering practice able to explore the system and the changing environment, including the technology in its contexts of design and use, and also, whenever feasible, able to anticipate the consequences of technology use. We need an ethical mind able to produce sustainable design or [26], better, an effective design that generates sustainable values [20], [9], [32]. Just to be clear, we think that soft sciences are often much more difficult in action (practice) than the hard ones [6], [62].

With this paper, we intend to construct a narrative proving that social sciences represent a primal influence in engineering design, in engineering practices, and consequently [34], in designing the learning models and [67] school's approaches that should align with this practice reality. So, we pretend to point some directions for improvement in engineering education and engineering practices. We use different supports glued with narrative. This tentative approach looks adequate as theory results from observation and reflection, comparing incidents and integrating different phenomena [25], [6]. With a story-based strategy we have our progression open, open to adaptive change and emergence of new conditions. We also explored conjecture as a "methodological" approach, [70], [71].

Concerning research approaches in an ontological and epistemological perspective [22], we can say that the gap between the view we explore in this paper and the usual way of seeing these things can be paralleled by the gap between the way Positivists (Comte) structure their actions and thoughts, their concern on measuring and quantifying, and the way Interpretivists (Husserl & Schutz) try to understand systems (systemic reality) and things, usually within situational qualitative reasoning. Interpretivists are generally grounded in phenomenology, particularly aligned with permanent changing environments and evolving complexity. The rate at which environments change and complexity of situations are growing to levels never experienced, demanding for new approaches and visions. Our intended results are assumedly discursive, we think that if we stress some evidences they can perhaps be understood and eventually internalized and, as a result, important attitudes towards engineering and engineering teaching/learning can be moulded. Our paper doesn't intend to be an ultra-robust final proof, but just an argument on that way. We believe that there are many confusions with what knowledge really is and we defend that knowledge is completely different from information, a typical confusion. Information is a base for knowledge, as knowledge is a base for action. We often think we know and we don't know, other times we say we know but we didn't really internalize what the situation really is. Often we don't know enough about the context in which we are operating, and most part of the times engineers doesn't have the abilities to understand environment. In fact, environment is a place, better, a space, of doubts, uncertainty, discussion, negotiation, assignments, conciliation and stabilization. A space of risk. A space that is not purely technical, not only social, but sociotechnical.

This paper is structured in sections, this introduction, followed by the roots of the problem (the divide), then a description of things around what we call the first engineering revolution, then we move into what is necessary to prepare and consolidate what we refer as second engineering revolution, then we concentrate on adopting and stimulating (frieze) the effects of this second revolution, after we describe two simple case studies (more examples then case studies), and finally we appoint some reflexions and state some conclusions.

II. THE DIVIDE AND EXPRESSION OF NEEDS

What was a philosopher in Hellenic times? Philosophers were integrated systems with different capabilities and competences, always ready to learn, knowledge in progress. Greek philosophers reflected about the reason of things, constructed reasons and explanations for objective and subjective things, interpreted reality, but they were also many other things. They could act as doctors, diagnosing and healing people, as engineers, developing technological artefacts, as jurists, preparing, commenting and applying laws. They were also poets as they expressed and analysed emotions, they were above all a person in full, people of great knowledge, knowledge constructed through deep reflection, and experiment, knowledge always in progress. Their maturity was earned by observing, experimenting and testing, and being always developing well-organized mental models.But let us jump some centuries, from the splendour of the Hellenic world into the XVII century. The XVII century was the time where René Descartes attained his huge success. Philosopher and "modern" scientist, Descartes wrote some important books and established some very strong points about reason, and reasoning. Descartes pearls dominated occidental culture, namely scientific culture [6].

One of these pearls was the Discourse of Method. Descartes was someone very influent in occidental education, on the way how we think and how we learn. He built an architecture of knowledge that marked our occidental way of thinking. For example, the dualism between spirit and body, and the mechanist reasoning, that is, the need to divide and decompose in order to understand [16]), these were pillars of Descartes philosophy, they imposed themselves in the world, and now they are being questioned [18].This Cartesianism divide, always present in the evolution of occidental knowledge, and very present even today in occidental science, is the basis for our reasoning in the two revolutions.

Cartesianism expressed a global philosophy, a philosophy of everything. Its starting point was to reject all authority and question everything. So far a very good working principle in science. Descartes claimed cogito, ergo sum, or I only exist if I'm able to think. Encouraged by his own success at the time, Descartes developed a rationalist philosophy that was the ground for part of the "modern" occidental thinking. A central idea in this philosophical approach was the dualism between mind and body. Mind and body being the two basic substances of reality. In Descartes view, each of these substances can exist separately, body as realized in inanimate objects and lower forms of life, mind as realized in abstract concepts and mathematical algorithms. This divide, however, was not invented by Descartes. It is mainstream since the origin of times. Aristoteles and Plato already discussed these matters. Aristoteles, Plato's disciple, stated that it was an error, a Platonic error, to consider a duality between idea and form. Modern times and the development of neurosciences (mechanisms of mind) give reason to Aristoteles. Form cannot live independently of physical content, and it is not independent of perception, a translation from sensations [45]. And Aristotle was right, Aristotle's Holism stated that knowledge is derived from the understanding of the whole and not of the single parts [39].

Based on the work of neuroscientists [7], [18] and modern theory of systems [17], [15], [38], this divide, as strong as it is, or was, became to blur and now we know that there are no pure rational approaches as well as there is no pure emotional reasoning. What we experience and use in our professional and individual life, the substrate in which we base our decisions and actions, is a blend of both approaches. At any activity of mind and body we use reason and emotion, interconnected, mingled, Yin and Yang. Apart from that, things are naturally complex and intricate. Boolean algebra, based on Aristoteles logic, was the basis for modern computers. Boolean algebra was born of philosophy (with some mathematics). All things blend, all things integrate and interact. Facing our divide, there is a need for conciliation [44]. We need to break the divide that separates things in parts, preventing us of understanding the world, natural things and technologies.

In a survey in Australia, employers were concerned with the lack of social literacy and human competences in engineering graduates [8]. This skills and competences are important by themselves, but they also provide significant improvements in critical thinking and capacity to formulate important questions. In a compared study between engineering [47] and humanities students, altogether with the work of Hudson [29] they could conclude that engineering students were more convergent, focused in solutions, but less conceptual and weaker in conceptualization. Enduring engineering students with humanities and social sciences skills will provide stronger and more effective actors in the entire system, they begin to be able to conceptualize as well as deep down in focused objectives. In a similar line of reasoning [4] Ashby recommended that, to explore a wider view and mature conscience, engineering students should explore subjects as diverse as ethics, and industrial and technology history in their engineering curricula.For example, [72] stated that in the engineering curricula 30% should be social sciences and humanities; The Accreditation Board for Engineering and Technology [1], a body responsible for the accreditation the different USA engineering courses, stated for a minimum of 12,5%; the similar body in Australia, Institution of Engineers Australia, set for 24%. There is a tendency for a future alignment of the technical and the social in order to pacifically promise a better future, with engineers better prepared to tackle XXI century.

III. ENGINEERING BASIC GROUNDS AND THE FIRST ENGINEERING REVOLUTION

Engineering practices were born with the primitive man, creating instruments of war, hunting and sheltering. First as hunter-gatherers and tribe lieders, after in organizations as company professionals and specialists in action, always inventing and designing artefacts inscribed in different tools, embodying patterns of use, translating innovation in a variety of technologies. Considering the ill-defined structure of most engineering problems, we must recognize that the positivist paradigm ruling in engineering schools and some of the strategies adopted to teach, as the problem-solving approach, doesn't prove to be the most fruitful. It becomes more problematic when we observe the same limitative approach in research.

Part of the engineering research production is based on the deployment of hypothesis that needs to be validated, usually applying statistics. That kind of research is focused on validating the hypotheses. But, as Popper [51] says, this isn't a sound prove, in fact, knowledge creation and discover of new realities cannot be attained this way, we can prove a hypothesis is wrong, we can never prove it is right. Furthermore, hypothesis cannot be static, they drift along the development of a technological solution. So, this approach is not recommendable.But returning to the problem-solving paradigm, why are engineers being given well defined problems with well-defined data sets and why are they trained to apply basically the fundaments (physics and mathematics) to solve this class of (closed) problems? Two errors in the same take! Physics and mathematics are crucial in the development of engineering models but they need to be paced by the needs, by the social value they must provide, according to environment and its dynamics.

In fact, the most important approach for engineering problems is much more the problematization, the way we consider and define the problem and the negotiations and coalitions we need to arrange and construct in dealing with the problem itself and all the technical and social settings that envelops the problem. We need to study the problem within its network of stakeholders. To align complex sets of different factors and technologies within a same goal is only one of the topics in this concern (Callon, 1986), [2]. In a similar perspective Donald Schön [57]) referred to problem setting and Michel Callon [14] referred to actor networks, detours, translations, alignments, immutable mobiles, and obligatory passage points.

IV. PREPARING FOR THE SECOND REVOLUTION

Engineering practice is becoming more and more the domain of integrated teams, carefully built and motivated, well managed and of course well prepared [58]. FET advisory Group stated some of the strong needs to 2020 (now we are already there) - technological innovation need to pay close attention to the social contexts in which it is to be placed. The engineer as an individual used to be a lonely runner, a hero. Not anymore, nowadays the engineer is impelled to work within a team, not only because of the increasing specialization of action but also because action is taken in complex systems and complex environments, where change occurs and new problems emerge constantly, and that calls for different expertise. So, due to this specialization-systemic facet of technologic artefacts design, teamwork is essential [54]. The challenge is to act in teams in situated problems and to be able to formulate problems and resolve them using experience, knowledge, sensibility, creativity and innovation. The challenge is link design and development with value (social, users, stakeholders, organizations).

Some decades ago, in the fifties in the United States, in a meeting of the best engineering schools, social science was considered to be mandatory in the engineering curricula. "In professional engineering practice the "new situation" often involves social and economic as well as technical elements, and these are not entirely separable", Grinter report [72], pp. 79. Engineers alone are no longer viable, they need collaborative teams [64], and engineer's expertise is no longer enough, technology and social are intertwined [72] and the engineer needs to, on top of his technological background, develop a social mind [46]. We need engineering education oriented to this goal [28], [12], we need engineers to be more complete. The formulation of the problem, the problematization, is one of the most significant and noble moments of the engineering design act. Solutions are much more the result of negotiations then the strict result of a plan. Negotiating amid all stakeholders, producing good consequences to all of them [16] in a win-win basis, is the only basis that can ensure sustainability, effectiveness and quality. And we need to understand that we are always acting in a context of scarce resources, in what respects work availability, financial availability, infrastructure reliability, and knowledge readiness [44]. Scope management has to do with all these variables in a systemic proportion [19] and is inhabited with technical and social factors, constrains, and opportunities.

Considering what we just stated, why are engineering schools insisting in training future engineers in problem solving only? We risk having good solvers of wrong problems! This traditional and wrong approach is limiting the value of engineering practice [11]. To confirm what is said we can address the work of [42], [52] as we could refer many others, but we can also consult statistics of project success. Worldwide these statistics [53], [59], [35] wherever they come from, show an embarrassing level of failure, with high rates of projects cancelled and running under specifications (either in cost, time, or scope, usually with cumulative problems in all the referred dimensions) (Williams, Figueiredo and Trevelyan, 2013). And projects, technological projects, are at the core of engineering activity, they are the engineer activity by excellence. In fact, engineering, these days, has to absorb and integrate concepts from the social sciences in order to respond at its best to the challenges of our modern life [12]. Distributed power and boundary issues [49] that change quicker and quicker drives engineers to new ways of acting.

This new conditions demand new ways of preparing our students. Engineers have a strong scientific background, so the phrase written by Star and Griesemer applies also to them: “Scientific work is heterogeneous, requiring many different actors and viewpoints. It also requires cooperation. The two create tension between different viewpoints and the need for generalizable findings” [60] (pp 387), [61].Synthetizing, engineers need a social mind [31], need to formulate problems, need to train qualitative reasoning, must be trained in understanding contexts, need to develop or improve negotiation skills, should practice in constructing meanings, must practice critical thinking, should absolutely consider soft skills as a very important topic in their education. Engineers need to recognize that they are obliged to internalize knowledge, as well as externalize. They need to better understand the world, to live with the world. Adding to these topics that are more social, engineers also need to develop competences to analyse and evaluate risk.

V. ADOPTING THE SECOND REVOLUTION, TWO SIMPLE CASES

Engineering Project Management” course, Instituto Superior Tecnico, Universidade de Lisboa, Portugal, (IST, UL, PT) : We focus on engineering project management, a topic that deals with different areas. To develop social skills and a social awareness in engineering settings where technology tends to play an important role [48] we explore project [69] oriented education practices, defining goal oriented tasks [36], cultivate self-sufficiency of the student (they have a “space” to try and experiment by themselves) [33], and if possible (it is possible in the second semester, not the first) we develop an experimental competition just to give the feeling that things are for real, and with consequences. We also try to push some limits and constrains in order to impose the shape of ambiguity and extrapolate the potentiality of eventual risks. Risk analysis (Monteiro de Carvalho et al, 2015) and estimating risk impact, duration and costs (educated guessing) should be pushed as far as possible, as they represent major constrains/opportunities in the planning and development of projects. So, these aspects should be covered in educational initiatives, (and they rarely are).

Our project management course takes all a semester and is exercised in the first and second semester in IST, Universidade de Lisboa. We have students from electronics (project management is mandatory in this master), engineering and management of energy (optional), mechanics (optional), physics (optional), biomedics (optional), and aerospatiale (optional). This project management course is a 4th or 5th year subject in a five-year engineering master in Electronics. The fact that the students are mainly last year students is good, but sometimes even in that situation they don’t have enough maturity. Very often students don’t have the maturity to appreciate subjects that, for them, are out of scope in their speciality, they are there to study technology, to solve problems, to calculate and explore quantitative reasoning! And we are insisting in exploring other goals as well.

We designed two training strategies that are particularly oriented to the described goal.

In the first strategy, we organize presenting/discussion sessions that involves all groups and takes all the semester long. We distribute project management papers from top journals, like International Journal of Project Management, or Project Management Journal, to the groups of students (normally four or five students per group). Each group has a paper to present in an appointed and scheduled PowerPoint session. In these presentation sessions, there are other two groups that studied the same paper to be presented and should question the presentation either in formal terms and in terms of content (was the presentation aligned with the paper? were there wrong translations?). This discussion should also extend to the value of the paper, and eventual critics to the authors. Groups are invited (and it is a component of the evaluation) to explore a critical view of the paper presented. These debates, moderated by the professor, which can raise new questions, take about one hour and a half. During the semester, all groups present once, and discuss twice, covering altogether three different papers. So, every student in the course, which is typically a 150 student’s course, will study in deep three top articles, and less deeply all the others articles distributed. This component helps to develop many important skills [43], and assures a kind of literature review in project management. This strategy acts as a very important cultural vector for project management.

The second strategy, training component is the planning of a project, with “real” data and constrains that just happen (or that we force to happen), or emerge during the semester [37]. Given the description of a project, groups using Microsoft Project assume reasonable settings and exerts their project management capabilities deciding on course of action, defining priorities, detailing resources, and advancing estimations. All the exercise is focused in project management processes so the specific details of the engineering problem are only addressed in very general and light terms. To be evaluated the students present a report (succinct narrative of assumptions, decisions and actions taken), the correspondent MS Project file, and a PowerPoint file used to further explain their project

Options to a jury in a live session. In this final presentation, the group has a fixed time to present the project and roughly the double to discuss it with the jury. The jury evaluates, taking information from the discussion, from the presentation (what is said and showed), from the MS file, and from the report. Students learn how to use MS Project by themselves, no classes on this topic. They all can download a copy of Microsoft Project to their own computer due to a IST partnership with Microsoft. This component exerts the ability to work autonomously [30] and learn with experiments, and in the course of the semester all students master MS Project just by using it within the project. To validate this assumption during the project discussion the jury asks any element of the group (or all of them) to explain options on the MS Project file. Learning MS Project by themselves and developing a solution for the (open) case we provided are activities that demand the need for autonomy, exercise problem formulation, and develop a basic condition for learning unbounded. It is also an activity were students explore situations, taking actions, having to reflect in qualitative terms, and needing to deal with risks, learning that sometimes there are not optimal solutions and our goal is the good enough [65]. Reality and nature are seldom optimizable.

What we described is not exactly a case, it is more like an example, a description of an evolving setting. But it is a case draft, a draft of a single case and, as Robert Yin [65] pointed out, it can be used to determine if the proposition of a theory is correct. It can help on validating the general approach.

Project" course, Engineering and Management Energy Master (IST, UL, PT) : The extended importance of soft skills, as we already stressed, is so noticeable that some companies are bypassing academic qualifications altogether and using their own methods to assess the candidates that apply to their calls. In 2015 the global accountancy firm Ernst & Young said that they were going to use their in-house assessment programme and numeracy tests. The CHRO of Ernst & Young explicitly said that "At EY [23] we are modernising the workplace, challenging traditional thinking and ways of doing things. Transforming our recruitment process will open up opportunities for talented individuals regardless of their background and provide greater access to the profession" [23].

Our project, a project-based learning approach, a workout for formulating problems to be solved and provide an integrated solution, is intended to exercise relational skills and problem formulation skills, along with collaborative/competitive abilities and critical thinking development. We also try to develop an ethical mind through two ethical seminars widely participated, but that is the matter of other paper. These days there is a crescent investment on HASS in engineering curricula [56], namely in the United States, and HAAS accounts for Humanities, Arts and Social Sciences and our effort is completely aligned with this concern. We have been insisting on problem formulation prior to problem solving, a task that prefigures a main teaching strategy in engineering schools. In real life, a big part of the work is concerned with understanding what is going on, what are people's needs, how can we design, develop or fix something. In this situated approach, we think engineers absolutely need problem formulation. Schön [32] called it problem setting, "But with this emphasis on problem solving, we ignore problem setting, the process by which we define the decision to be made, the ends to be achieved, the means which may be chosen. In real-world practice, problems do not present themselves to the practitioner as givens." [57] (pp 40). We could also say that formulating/setting is, more or less, the same Calon [14] and the sociologists of Actor-Network Theory called problematization. Not exactly the same but similar, and compatible.

In our classes, we choose a company, normally involved with innovation in the new energies sector (Eolic, PV, Bio-mass). With this company, we negotiate a concern and we clarify the company strategy, what they want with this experience with students. We ask them to provide a concern to guide the students in their work, a concern aligned with their strategy. Normally the company combines already known and explored situations, with experimental and innovative scenarios. Following this setup the company launches a need (always real, or at least basically real), a general problem with technological and business choices, to which they (in the company) are looking for an interesting solution. Our students, divided in heterogenic groups (preferably with students of different countries in a same group) will follow a step by step approach. Beginning with problem formulation, they evolve to a proposed final solution that needs to be aligned with the company strategy. This step by step evolution can be defined as control-gates of a learning project. This control-gates usually pass by what we call a literature review (first control gate), were students research about what exists (in the domain of the solution) and what are the trends both in terms of business model and technology. This stage ends with a PowerPoint presentation of the groups, followed by discussion. These discussions tend to be enlarged through the class and often contributes with corrections and exploring different paths, steering and tackling the problem differently.

The second control gate is the choice, validation and use of a business model. Another PowerPoint presentation with discussion about this topic. We must say that the discussion is held by the professor, the representative of the company, the presenting group, and all the other groups of the class. The third control gate is a technological model and a new presentation/discussion is performed. Finally, in the last control gate, students construct a final systemic solution, mingling technology and business. The idea is the "selling" of the solution (total approach) to the company. The spirit for the groups is that they need to sell their final solution to the company representative. The teacher and the element of the company write a short log with each presentation weak and strong points, lateral notes on the group and eventual details on particular students. These short evaluation is sent to the groups the same day of the session together with the mark each group had in the session. The teacher and the element of the company always act advising and coaching, all along the entire process. Our discussions sometimes propose redoing, thinking things in completely different terms, enduring resilience, a skill that all engineers should work on, developing it and making their will stronger and more focused.

We stress that, with the approach we described, we facilitate and promote group working, collaborative behaviours, and soft-skills development, improve problem formulation, explore autonomous work (decisions), practice qualitative reasoning, critical reasoning and the development of an ethical mind.

For years, the control gates of our approach were the ones described. From now on we are going to experience one more control gate. We noted that even though we stress the importance of paying attention to the other groups approaches, stressing that improving the capacity to hear and understand the others is fundamental, most part of the students of the groups were only concerned with their own work, their own problems and didn't even catch what the other groups were saying and presenting. So, we created a final extra control gate that is about selling a solution that is inseminated by pieces of work developed by other groups (business model, CANVAS, stakeholders, technological model). That is, each group should provide a new final solution with parts of the other groups presentations. And as well as the groups in the PowerPoints presentation need to explicitly show the source of their information (explicit reference, citation, paper, book), in this last stage they have to reference from which groups they took the parts they are using. And each group needs to try to "sell" this combined solution to the company representative. This experience is a little bit radical, but we believe it will be effective and actually providing very interesting skills. Groups need to decide which part or parts of other groups they should integrate (import), they need to work in a kind of sewing, adapting both the imported part and their one part, they need to feel that this hybrid solution is their own solution, in order to perform a convincing "sell".

This project takes all a semester and is exercised in the first and second semester at IST, Universidade de Lisboa. At the beginning of the semester we meet with the students, we explain what is the purpose of the project, we arrange the groups of students and we state a scheduling for the control-gates for all the semester, using about five sessions overall plus the one just described. In the first session, we play a kick-off meeting, the element of the company presents the company and the intended concern for the problem, talking about the range of expected solutions. Then in each session groups present their work using Power Point and we all discuss options and quality of the work in progress. In their preparation sessions, there is a strong component of working in group with full autonomy [30] and learn with experiments, with trials, and along the semester all students learn how to problematize as well as how to provide viable solutions. Solutions should be viable, technologically and financially, and they must be robust enough to be sustainable.

In either of the presented cases, we explore participatory methods [55], we coach students exploring co-opetition, [41], [10] meaning cooperation in competition (for their mark in the session, between groups, and for the student final grade in the curricular unit), and we facilitate the perception of exogenous variables (their potential treats and/or opportunity) [34], [36]. We always encourage the pursuit of prospective solutions within their operational contexts [4], see the solution, see the consequences, and whenever possible integrate stakeholders in the process [8]. We also explore the formulation of problems [2], [57], as an indissociated part of the engineering act and part of an obligatory path to an effective solution. We also explore the sense of risk and associated responsibility to any choice, and clarify that there are no settings without risk. Stakeholders are not passive actors in our plot, they change with time, they change entities, and positions, we need to be always negotiating with them [63]. In the first stage of our exercise stakeholders are one, in the second stage they are different, and so on. And all these factors are more or less simulated in our progress to the final solution. Our problematization always incentive an alert to eventual "disturbances" assuming that they are not side-effects, they are part of the problem. Apart from these considerations we have a very high percentage of students that really enjoys the experience and considers it very challenging and very educative. They all repute the experience as new, different from all the other subjects and they also consider it with a hard degree of difficulty. It is a fact that all referred skills grow with practice, which is a reason to create situations of practice, of exercise.

VI. CONCLUSIONS

Our main conclusions are general. Schools must adopt some new roles on engineering education in order to create more flexible practitioners and more educated engineers. Flexibility, ability to understand social things, ability to identify, recognize and formulate problems, creativity, negotiation and bargain abilities, and resilience, are among the top characteristics needed for modern engineers. These, on top of a good technological background. Our work looks relevant for the academic and practitioner community not because it is sound innovative, but because it can contribute as an alert. An alert to relevant actors in this community, in order to define adequate contexts and situational settings for engineering learning, and above all align goals with value for the market/community, recognizing that the social plays a fundamental part in our activity.

In preparing to the second revolution and through the second revolution the engineer grows wider, generates and accumulates more knowledge, expands its capabilities in transversal axis. Explores abilities to collaborate, work together, listen to the others, and develop a sense of the world and social values. These are now crucial topics to work on, to reflect upon, and to internalize. And the internalization of a habit [68], or a competence, takes time and effort, obliges adequate strategies, conscientious effort and alignment of purposes. Engineering education should address strategies to assure the necessary transitions to this paradigm. And internalization is not the same of "having heard", "I already saw it once", "we once talked about it", internalization is a multi-step approach, usually circular, sometimes within a painfully circulation of routines, that uses your knowledge or the one we are developing into a capacity to act. If you are knowledgeable you are able to do, to act, to create, to use, always in an adaptive and alert stance, not by habit or routine. If you are alert you are able to explore, to discover, to decide, to experiment, to give up, in a disposition that is cumulative to develop more knowledge.

It is mandatory to improve and enrich our knowledge base. Using a flexible roadbook comprehending different domains and forms (technical, social, law, norms, culture, common sense, ethics, and sustainability) always with a content on engineering, we explore how to make better decisions, how to better undertake problem formulation and how to solve things under project management approaches. Adjusting quality and ethics, we discuss about perceiving a sense of value (social, economic, sociotechnical, organizational, project), as well as we define good practices in management. Acting in these specific settings, engineers gain a different conscience of the engineering act, and the act itself transforms and expands. As action depends on negotiations among the different actors, and problems and constrains emerge continually, engineers gain a different sense of mission and readiness to action that positively affects the way they behave, design and decide their action. This approach to the engineering practice tends to strongly link the situated problem (framed) with the context, to understand technology as a sociotechnical thing, to define a network of aligned interests, where values are permanently negotiated, renegotiated, and finally shared among stakeholders.

For example, from being guided by a stable plan of action, engineers now need to be attentive and ready for the emergence of action, anticipating and reacting to what drops from action in its core concern and also in its limits. That means engineers need to adapt to plans in progress, based on a continual and evolving drafts, an activity like craft, as Mintzberg [40] would surely say. Engineers need to be attentive to emergent details, reactions, constrains and opportunities. Complexity and the need for negotiating courses of action, as well as definition of requirements and other designing details [13] lead to the need of socializing [44]. Socializing, by debating, reflecting, internalizing and experimenting that's how knowledge is created. We believe that to internalize knowledge we need a second (and third, and fourth) round of action-reflection, because learning [5] is an elaborate process that happens in recursive cycles, just like the slices of an onion [3].

The knowledge produced is cumulative and contributes to the maturity of minds and quality of decisions and actions, as well as to the learning capacity and ability to identify situations and problem. More mature and knowledgeable we are, the more deep goes our understanding. This cumulative knowledge leads us to understand situational social relations and tensions that always exists, and continually emerge, but often are disguised and hidden. The production of knowledge is both situational and predictive, as knowledge is cumulative and a support for the learning process. But, more importantly, it is also a support for what you can do, kind of a tacit limit to our abilities and potential performance. We talk about an engineering able to explore the system in consonance with the changing environment, technology in its context of use and also, whenever feasible, able to anticipate the consequences of its use. We look for effective designs that generates sustainable value [20], [9].

And we intend to do it from the whole to the parts. From the whole to the parts, versus from the parts to the whole. These two paradigmatic approaches are so strong that they can facilitate or difficult things, namely the way we see and feel reality, roles and goals. From the parts to the whole is probably useful for a set of situations that are everyday more specific, basically founded in mechanistic reasoning. From the whole to the parts is more holistic, based on a systemic approach and has an advantage on the way links and connections among parts are percept.
In our view, from the whole to the parts is recommended to a significant number of situations. We look at the overall system and understand how parts are linked, we explore this links and connections, and only then we invest on the details, understanding or designing the parts. That is the way a system should be designed (or understood) as a whole, and parts are designed (understood) in their interrelationship with this whole.

In fact, as neuroscientists Bechara and Damasio [66], as well as Goleman [27] clearly described, the mechanistic approach stated by the Descartes legacy [18] is no longer the best approach to deal with complex systems. Engineering needs to enlarge its duties, the engineer needs to become more like a person in full, more versatile and with and extended conscience for interconnection of things. Organizing group work over the work of other groups like we propose in control gate 5 achieves two important goals. Students begun to pay full attention to what their colleagues do and present, so knowledge contexts circulate more easily and effectively in the classroom. Secondly the students have to explore their creativity, in fact after constructing their own model, they have to construct a new model made of parts presented by colleagues. This stimulates creativity, but also activates socialization among groups which is a master objective in our learning model. This is an effective attempt to make students collaborate in competition. This is coopetition (cooperative competition), something that the authors Branden burger, and Nalebuff so well defined in their book [65]. This is an interesting concept because students need to collaborate, and they usually do as elements of a group. They collaborate among them, which is good but they do it in a very close and restrict space of ideas. Apart from that they usually look at the students in other groups as competition, from who they sometimes hide information and discoveries, using strategies of defence and fight, not strategies of design and development. With coopetition, they understand that they can profit from the work of their concurrence if they adopt practices of reciprocity. And these practices are welcome and necessary in our real-life practice. If you dispute a specific space and more competition enters that space, the space grows and enlarges, doesn't meaning that your share shrinks. Usually your share also expands.

Another topic that we are able to comment is the problem solving/formulating. It is clearly noticeable the evolution during the semester. At the beginning students (groups) begin working without knowing what they intend to do. They do it because they are used to do it, they first do, then they think, it is what usually happens. Business as usual. This approach can work if you are solving well delimited problems, with precise data, stable environments and no uncertainty. But if the problem you are solving is the one you are yourself defining and constructing, this precipitation to the solution doesn't work at all. In this kind of open-handed problems, discussions are fundamental. Going explicitly around the purpose of something they soon understand that to define well what they have to do, why they have to do it, and how they should do it, analysing consequences of this chain of decision, is a complex task that only can be taken with huge reflection. And, in this reflection the cooperation (discussing, debating) between different minds usually bring better results.

Another thing that shoes good results in our research is our purpose of integrating technology and business. Before this approach, some of the solutions proposed by our students were widely non-feasible, as well as their attention to costs and ecology were both inexistent. Non-feasibility was usually due to excess of resources consumed, and investment needed quite above reasonable and possible. With our combined approach (technology and business) students begin to be obliged to justify their options, as well as they need to quantify investment, operational costs, and risk. They need to have an understanding of the socioeconomical system. That means, students are obliged to immerge in reality, and they need to be able to convince the jury of their choices. They need to define solutions that can survive, a way of saying they are looking for sustainable solutions.

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REFERENCES

1. ABET (Accreditation Board for Engineering and Technology), (2002). Criteria for Accrediting Engineering Programs: Effective for Evaluations During the 2002-2003 Accreditation
2. Argyris, C., and Schon, D., (1978). Organisational learning: A theory of action perspective. Reading, Mass: Addison Wesley

3. Asher, Dan, Micha Popper, (2018). Tacit knowledge as a multilayer phenomenon: the “onion” model, Emerald Publishing Limited
4. Ashby, E., (1966). Technology and the Academics - An essay on Universities and the Scientific Revolution, London: Macmillan Cycle
5. Barr, Robert and John Tag, 1995, Change, November/December 1995, pp. 13-25. Reprinted with permission of the Helen Dwight Reid Educational Foundation. Published by Heldref Publications, 1319 Eighteenth St., N.W., Washington, D.C. 20036-1802. Copyright 1995.
6. Berliner, David, (2002). Educational research: The hardest science of all, *Educational Researcher, 31, 18-20.*
7. Bechara, A., H. Damasio, D. Tranel and A.R. Damasio, (2005). The Iowa Gambling Task and the somatic marker hypothesis: some questions and answers, in *Cognitive Sciences Vol.9 No.4 April*
8. Beswick, D., Julian, J., and Macmillan, C. (1988). A National Survey of Engineering Students and Graduates, in (Williams, B. Chairman) Review of the Discipline of Engineering, Canberra: Australian Government Publishing Service, vol.3, pp. 39-105
9. Bocken, N.M.P, Short, S., Rana, P., Evans, S., (2013) A value mapping tool for sustainable business modelling, *Corporate Governance, Vol. 13 Iss: 5, pp.482 – 497*
10. Brandenburger, Adam, Barry J. Nalebuff, 1997, Co-Opetition, Profile Books Ltd
11. Bransford, John, (2007). Preparing People for Rapidly Changing Environments, Journal of Engineering Education, January 2007 (Editorial)
12. Bromley, Allan, (1995). in Engineering Education: Designing an Adaptive System, Board on Engineering Education, National Research Council, ISBN: 0-309-52051-7
13. Bucciarelli, L. L., (1994). Designing Engineers, Inside Technology. W.E. Bijker, W.B. Carlson, and T.J. Pinch (eds.), and Cambridge, MA, MIT Press Burger, S. (2015). Industry 4.0 requires factories of learning, Creamer Media Engineering News. [Online] Available at: http://www.engineeringnews.co.za/article/ industry-40-requires-factories-of-learning-- festo-2015-04-24/rep_id:4136 [Accessed 12 January, 2016].
14. Callon, Michel, (1986). Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay, in J. Law, Power, action and belief: a new sociology of knowledge? London, Routledge, pp.196-223
15. Capra, F., (1997). The web of Life: A New Scientific Understanding of Living Systems, Anchor edition (September 15, 1997)
16. Cipolla, Carlo M., (1988). Allegro ma non troppo, Il Mulino, Italy
17. Checkland, P, (1994). Systems theory and management thinking. 09/1994 In: *American Behavioral Scientist. 38, 1, p. 75-91. 17 p.*
18. Damasio, António, (2005). Descartes Error, Penguin Books
19. Dettmer, H. William, (2006). Systems and Constraints: The Concept of Leverage, *Goal Systems International*
20. Dutta, E. A. B., Sengupta, Ipshita, (2014). Engineering and Sustainable Environment, *International Journal of Engineering Research and General Science Volume 2, Issue 6, October-November*
21. Engineering Practice in a Global Context: Understanding the Technical and the Social Hardcover – 3. September 2013 edited by Bill Williams, Jose Figueiredo, James Trevelyan
22. Engineering Identities, Epistemologies and Values: Engineering Education and Practice in Context, 2015, Philosophy of Engineering and Technology 21, Volume 2, Springer, edited by Steen Hyldgaard Christensen, Christelle Didier, Andrew Jamison, Martin Meganck, Carl Mitcham, Byron Newberry
23. EY, (2015). EY transforms its recruitment selection process for graduates, undergraduates and school leavers, Building a better Working World, 03 August 2015FET, Future & Emerging Technologies Advisory Group (FETAG), European Comission
24. Figueiredo, A. D., (2013). On the historical nature of engineering practice, in Engineering Practice in a Global Context: Understanding the Technical and the Social, Eds. Bill Williams, José Figueiredo, James Trevelyan, CRC Press
25. Gilgun, Jane F., (2001). Grounded Theory and Other Inductive Research Methods, In “The Handbook of Social Work Research Methods” Edited by Bruce A. Thyer, SAGE Publications, Inc. City: Thousand Oaks Print, pages 344-364
26. Giudice, Fabio, (2013). Eco-Packaging Development Integrated Design Approaches, in Handbook of Sustainable Engineering, Springer
27. Goleman, Daniel, (1985). Vital Lies, Simple Truths: The Psychology of Self Deception, Simon & Schuster Grinter, S. (1955). Final Report of the Committee on Evaluation of Engineering Education, Journal of Engineering Education, September, p.25-60.

28. Hynes, Morgan, Jessica Swenson, 2013, The Humanistic Side of Engineering: Considering Social Science and Humanities Dimensions of Engineering in Education, Journal of Pre-College Engineering Education Research (J-PEER), Volume 3, Issue 2, Article 4
29. Hudson, L., (1975). Human Beings: An Introduction to the Psychology of Human Experience, London: Cape.
30. Hyldgaard, 1918, Engineering Identities, Epistemologies and Values: Engineering Education and Practice in Context, 2015, Philosophy of Engineering and Technology 21, Volume 2, Springer, edited by Steen Hyldgaard Christensen, Christelle Didier, Andrew Jamison, Martin Meganck, Carl Mitcham, Byron Newberry
31. Cooley, Charles H., 1918, The Social Process, New York
32. Ihde, D. (2008). The designer fallacy and technological imagination. In P. E. Vermaas, P. Kroes, A. Light & S. A. Moore (Eds.), *Philosophy and design (pp. 51–59). New York: Springer*.
33. Kasher, Asa, (2005). Ethical Perspectives, Journal of the European network, 11, 1, ps. 67-98, European Centre for Ethics, K.U.Leuven
34. Kendra, James, Joanne Nigg, (2014). Engineering and the social sciences: historical evolution of interdisciplinary approaches to hazard and disaster, *Journal of Engineering Studies, Volume 6, 2014 - Issue 3: Engineering Risk and Disaster, Pages 134-158*
35. KPMG (2017). Driving business performance Project Management Survey 2017
36. Lappalainen, P., (2011) Can and Should Social Competence be Taught to Engineers? *International Journal of Engineering Pedagogy, 1(3), 2011, pp.13–19*
37. Leon Liebenberg, Edward Henry Mathews, (2012). Integrating innovation skills in an introductory engineering design-build course, International Journal of Technology and Design Education 22(1):93-113
38. Meadows, Donella H., (2008). Thinking in Systems, Chelsea Green Publishing
39. Mele, Cristina, Jacqueline Pels, Francesco Polese, (2010). A Brief Review of Systems Theories and Their Managerial Applications. Service Science 2(1-2):126-135. https://doi.org/10.1287/serv.2.1_2.126
40. Mintzberg, Henry, Joseph Lampel, (1987). Reflecting on the strategy process, Sloan Management Review Spring 1999; 40, 3; ABI/INFORM Global pg. 21Monteiro de Carvalho, Marly & Roque Rabechini Junior, (2015). Impact of risk management on project performance: the importance of soft skills, International Journal of Production Research, 53:2, 321Z340, DOI: 10.1080/00207543.2014.919423
41. Nalebuff, Barry, and Adam Brandenburger, 1996, Co-opetition, Harper Collins Publishers, HarperCollins Business
42. Nelson, R. Ryan, (2005). Project Retrospectives: Evaluating Project Success, Failure, and Everything in, MIS Quarterly Executive Vol. 4 No. 3 / September
43. Nguyen, Duyen Q., (1998). The Essential Skills and Attributes of an Engineer: A Comparative Study of Academics, Industry Personnel and Engineering Students, Global Journal of Engineering Education, Vol. 2, No.1 Nicholas D. Fila, Justin Hess, Avneet Hira, Cole H. Joslyn, DeLean Tolbert, Morgan M. Hynes, (2014). The people part of engineering: Engineering for, with, and as people, IEEE Frontiers in Education Conference
44. Nonaka, I., (1991). The knowledge creating company, *Harvard Business Review, November–December 1991, 2–9*
45. Nonaka, I, Takeuchi, H., (1995) The knowledge creating company, How Japanese Companies Create the Dynamics of Innovation, Oxford University Press
46. Ohland, Sheppard, Lichtenstein, Eris, Chachra, Layton, (2008). Persistence, Engagement, and Migration in Engineering Programs, Journal of Engineering Education, Junee 2008
47. Pan, R. (2011). Engineering as a caring and empathetic discipline: Conceptualizations and comparisons, Paper presented at the Research in Engineering Education Symposium, Madrid, Spain. October 3–7
48. Pertegal-Felices, M. L, J. L Castejon Costa and A. Jimeno Morenilla, (2010). Personal and Emotional Skill Profiles in the Professional Development of the Computer Engineer, International Journal of Engineering Education, 26(1), 2010, pp. 218–226
49. Philipose, Lily, (2010). Geramany: Hard facts about soft skills in universities, University World News, 03 October 2010 Issue No:142
50. Picon, Antoine, (2004). Engineers and Engineering History: Problems and Perspectives, *History and Technology, Vol. 20, No. 4, December 2004, pp. 421–436*
51. Popper, Karl, (1963). Conjectures and Refutations: The Growth of Scientific Knowledge, Taylor & Francis Ltd, 2nd Revised edition, 2002

52. Prabhakar, G. P. (2008). What is project success: A literature review. International Journal of Business and Management, 3 (9). pp. 3-10. ISSN 1833-3850 Available from: http://eprints.uwe.ac.uk/14460
53. PMI, (2017). A Guide to Project Management Body of Knowledge, 6th edition
54. Riemer, Marc J, (2002). English and Communication Skills for the Global Engineer, Global J. of Eng. Educ., Vol.6, No.1 © 2002 UICEE Published in Australia
55. Rodriguez, Arturo, Elena Cavieres and Catalina Negrete, (2014). Effect of Participatory Methodologies in Academic Performance, 4th International Conference on Education, Research and Innovation IPEDR vol.81 (2014), IACSIT Press, Singapore
56. Rojter, Josef, 2004, The Role of Humanities and Social Sciences in Engineering Practice and Engineering Education, International Conference on Engineering Education and Research "Progress Through Partnership", Ostrava, ISSN 1562-3580
57. Schön, D. A., 1983, The Reflective Practitioner: How Professionals Think in Action, New York, Basic Books
58. Schmidt (Janet, Linda and Paige), (2006). Besteams: A Curriculum for Engineering Student Team Training by Engineering Faculty, 2006, American Society for Engineering Education, 2006
59. Standish Group (2015). Chaos Report
60. Star, Susan Leigh, edited by Geoffrey C. Bowker, Stefan Timmermans, Adel E. Clarke, and Ellen Balka, (2015). Boundary Objects and Beyond, Working with Leigh Star, MIT Press, Chapter 7, p. 171
61. Star, Susan Leigh and R Griesemer, (1989). Institutional Ecology, Translations and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39Social Studies of Science, Sage, Vol 19, 387-420, Page 387 (Abstract)
62. Strobel, J., Wachter Morris, C., Weber, N., Dyehouse, M., Klingler, L., & Pan, R., (2011). Engineering as a caring and empathetic discipline: Conceptualizations and comparisons. Paper presented at the Research in Engineering Education Symposium, Madrid, Spain, October 3.7
63. Vance, Rupert B., 1945, Toward Social Dynamics, American Sociological Review, Numer 2, Volume 10
64. Vincenti, W. G., (1990). What Engineers Know and How They Know It: Analytical Studies from Aeronautical History, Baltimore, The Johns Hopkins University Press
65. Yin, Robert K., (1981). The Case Study Crisis: Some Answers Administrative Science Quarterly, Vol. 26, No.2
66. Bechara, A. & Damasio, A.R., 2005, The somatic marker hypothesis: a neural theory of economic decision. Games Econ. Behav. 52, 336-372
67. Chandrasekaran, Sivachandran, Riyadh Al-Ameri, 2016, Project/Design Based Learning Approach, iJEP – Volume 6, Issue 3, 2016
68. Lucas B. and J. Hanson, 2016, Thinking Like an Engineer: Using Engineering Habits of Mind and Signature Pedagogies to Redesign Engineering Education, iJEP – Volume 6, Issue 2, 2016
69. Terrón-López, M.J., M.J. García-García, P.J. Velasco-Quintana, M.C. Gaya-López and J.J. Escribano-Otero, 2015, Design and Implementation of a Comprehensive Educational Model: Project Based Engineering School (PBES), iJEP – Volume 5, Issue 3, 2015
70. Sandoval, William, 2014, Conjecture Mapping: An Approach to Systematic Educational Design Research, Journal of the Learning Sciences, Volume 23, 2014 - Issue 1
71. Bland, Dori c., Hjalmarson, Margret, Nelson, Jill, Samaras, Anastasia, Applying Conjecture Mapping as a Design-Based Research Method to Ex- amine the Design and Implementation of a Teaching Development Project for STEM Faculty, American Society for Engineering Education, 2017, Paper ID #18731
72. Grinter Report, Summary of the Report on Evaluation of Engineering Education, Journal of Engineering Education, Sept- ember, 1955 pp. 25-60.

ABOUT THE AUTHOR

Jose Figueiredo is an Electronic Engineer, with an MBA, and PhD in Industrial Engineering. He was a Professor of Project Management in Engineering, Project in Engineering and Management of Energy, Contexts for learning skills, and Sociotechnical approaches to engineering design (using Actor-Network Theory). He is from the department of Engineering and Management (DEG) in IST (Engineering Faculty of the Lisbon University). He is now retired but keeping a leading position teaching Project in Engineering and Management of Energy (PEGE), a terminal subject in the Master of Engineering and Management of Energy in IST. He leaded different projects both academic (with FCT – Portuguese Science Foundation) and as services, as well as consulting with engineering companies. He currently runs a professional Post Graduation course following a partnership with

Engineering Nacional Council. This course is a IST Post Graduation course, third cycle. He supervised many doctorate students (he is still supervising doctorate students now) and many, many master theses. Articles published can be consulted at:
https://scholar.google.com/citations?hl=en&user=RgnbwvsAAAAJ&view_op=list_works&gmla=AJsN-F4uSAro8znMg1OFbiMjpIwS7vMx_vypaUoc009wlYFJM6un8ogmiAar1y3RIrwLeahX0qrkB-fIKQ86fW4roSQPYc-Ej85wWcvgHB92vOuf8zcf4hA&undo=untrash_citations,qjMakFHDy7sC