

Lean Engineering Education: bridging-the-gap between academy and industry

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Abstract—This paper presents Lean Engineering Education (LEE) as an curricular innovation in the Engineering courses. It provides a discussion, mainly based on literature and informal dialogues, about the disconnected world of academy and industry and the demands for new educational methods and strategies. Additionally, it defines LEE as also the principles inherent to this and describes how LEE addresses two complex challenges faced by Higher Education Institutions: the globalized marketplace and the right skills from industry perspective for engineering graduates.

Keywords—Lean Engineering Education; systems thinking; sustainability; ethics; competencies

I. INTRODUCTION

Engineering Education (EE) is facing more challenges than before due to, by one hand, the globalization of goods, services and resources market and, by other hand, globalization of problems. These challenges need globalized solutions provided by whole-systems thinking and eco-sustainable solutions. In the past was common adopt one-sided solutions by ignorance or ingenuity or just greed such as putting in neighborhood backwards (or even said, to send to developed countries) the toxic residues from production or off-shore production to explore low wages or under-regulated work conditions. This unacceptable behavior is a critical problem and who practiced these bad solutions feel comfortable and safe, in their “own world”. Today, in a globalized world, these problems are recognized as problems of all, not of this or that company. These problems have financial, social and environmental impacts that return to their sources and blow out in companies’ faces, provoking, many times, their bankrupt, being the worst the tragedies tracked by the way (country losses, unemployment, pollution, ...).

Engineering Education system must engage students in this globalized world since graduate engineers needs to understand these dimensions and be aware of the impact of their bad decisions and solutions designed. At the same time, EE must

prepare them to be involved in company objectives and mission, helping company to make profits since this does not go against others or the environment. Many companies are achieving these two-fold objectives: being globally competitive and making profits in a sustainable manner. Such examples are Toyota Motor Company, Bosch Company, General Electric Company among others important companies. These have been followed Lean Production model management [1] that had his roots in Toyota Production System (TPS) [2][3].

Normally, a fresh graduate engineer when enter in one of these companies will be trained in the company model management principles and tools. All over the world companies are adapting Lean Thinking principles [4] to their own mind-set and culture [5]-[19]. So, it is clear that Lean is well accepted internationally among the companies. For this reason the papers authors believe that Lean provides the ideal platform to educate engineers for the workplace. This is discussed in this paper: how Lean bridges the gap between academy and industry, providing the competencies to the engineering graduates that industry needs.

II. BACKGROUND

This section discusses the challenges faced by Engineering Education (EE) in nowadays, highlighting some important reports describing these challenges. Additionally, Lean Production definition and Toyota Education Model characteristics are presented.

A. Engineering Education Challenges

The challenges of EE have been a theme effervescent in the community, at least, more than a decade. For example, Rugarcia et al. [20] and Felder et al. [21] put the challenges faced by the engineers in the beginning of the century as: 1) the proliferation of information; 2) the need for multidisciplinary for technological development; 3) the globalization of markets; 4) the endangered environment; 5) the emerging of social responsibility; 6) the need to participate in corporate cultures

and 7) the need for the rapid change in educational adaptation. They also discussed how they could be educated to develop the critical skills in order to be prepared to face these challenges [22]-[23] and the need to educate the academy in order to them learn how to teach [24].

Meanwhile some reports providing visions and roadmaps for the future of EE were published [25]-[33]. All reports have in common the concern to better educate engineers to a society that had changed and the need for the academy be aligned with these changes. Their concern is also the urgent need to address Grand Challenges of Engineering [30] but, also the 15 Global challenges facing humanity [31]. Engineering Education also has an important role to help United Nations Development Program (UNEP) to achieve the 8 Millennium Development Goals that were signed by 189 nations in 2000 to free people from extreme poverty and multiple deprivations [32].

Sometimes, the trend is to think that all is designed and invented but looking to the challenges and goals described above much more is needed. The Engineers' role in society, is emphasized by a report from UNESCO [29] that reinforce Engineering Education role in training well young engineers. This report highlighted the risk for Engineering Education and society by the cuts in funding due to the current economic crisis. Also, it recommend some changes for universities: *"University courses can be made more interesting through the transformation of curricula and pedagogy using such information and experience in more activity-, project- and problem-based learning, just-in-time approaches and hands-on application, and less formulaic approaches that turn students off. In short, relevance works! Science and engineering have changed the world, but are professionally conservative and slow to change. We need innovative examples of schools, colleges and universities around the world that have pioneered activity in such areas as problem based learning. The future of the world is in the hands of young engineers and we need to give them as much help as we can in facing the challenges of the future."* ([29], p.32).

Additionally, Graham [33] from Royal Academy of Engineering advised the need 1) to bypass the resistance to change and 2) to build systemic change as opposed to isolated instances of success in individual programs and on individual campuses. Another result from this report is the increase of the gap between what universities teach and what industry needs. Interaction between these two spheres is demanded to create a meaningful work environment. A world without this interaction *"...is inconceivable"* as Davey et al. [34] reported for the European Commission.

B. Lean Production and Toyota Education Model

Lean Production was the name used by Womack et al. [1] in a best-seller book to describe the TPS [2][3]. This name was used because they described the TPS as a system that is based in a key idea: *"doing more with less"*, i.e., less space, less resources, less stock, less people, less effort,... Using more than necessary is considered waste, so the focus is eliminate waste to achieve productivity increases and cost reduction.

National Institute of Standards and Technology (NIST) [35] defined Lean Production as *"... a series of tools and techniques for managing your organization's processes. Specifically, Lean*

focuses on eliminating all non-value-added activities and waste from processes. Although Lean tools differ from application to application, the goal is always incremental and breakthrough improvement. Lean projects might focus on eliminating or reducing anything a final customer would not want to pay for: scrap, rework, inspection, inventory, queuing or wait time, transportation of materials or products, redundant motion and other non-value-added process steps."

Another waste, being considered the worst of the wastes is the untapped human potential [36]. People is the most important asset in the Lean model, and since first publication in 1977 about TPS this was clear [37]. People make the changes happen or, by contrary, blocked these changes. Once well-succeed Lean implementation started, a company no more will be the same because thinkers will start to emerge as a collateral effect of Lean [38]. This is achieved because Toyota promote one of its pillars *"...capitalizing on worker suggestions"* [3] and defined an education model to spread the TPS by all factories. Under a slogan *"Making people before making products"* [39] they empowered people to search for continuous improvement at all levels within the organization.

Toyota Education Model was the name adopted by the learning system promoted by Toyota to transforms theirs employees in a community of scientists following the scientific method. By using a *"learning by doing"* system, the employees were allowed to experiment and learn with their own mistakes [40]. This learning system is considered the winning strategy to develop people in the TPS, being the "T" in this acronym also for *"Thinking"* [41]. Spear [42] describes the lessons learned in Toyota Education Model by the young managers to continue to sustain the strength of this company that appeals to experimentation and coaching importance.

Continuous improvement and respect for people were reaffirmed in 2007 as the two pillars of TPS system by a Toyota ex-president in an interview to the Harvard Business Review [43]. The others two pillars are the process and the philosophy or long term thinking. Also, Takeuchi et al. [44] after six-year study of Toyota companies, find out major contradictions that move Toyota forward, reinforcing that employees are free to express yourself giving contrary opinions and exposing problems without afraid of punishment.

The *"fireproof"* of this learning system was when TPS principles were applied for the first time outside Japan in Fremont, California (1983) in a joint venture auto-plant between Toyota and GM called NUMMI [45]. The system had worked and the company becomes an icon, working for almost forty years. He started by talking about culture change and how this has to do with mind-set [46]. In order to develop the right mind-set, Toyota also uses simple tools like: PDCA model, eight-step Toyota Business Practices process, A3 reporting system, 5Why's routine and kaizen events, amongst others. These simple tools help employees to identify wastes in the value stream in order to find solutions to eliminate them and create value for the client.

III. LEAN ENGINEERING EDUCATION

This section presents Lean Engineering Education (LEE) definition and principles. To understand the need of LEE, it is presented the disconnected between EE and engineering

professional practice (EPP) and the reasons for this as the demands for new educational methods and strategies in Engineering Education.

A. Disconnect between EE and EPP

The disconnected between EE curriculum and EPP was recognized by many authors referred previously. Also, Mills & Treagust [47] emphasized the following gaps:

- Engineering curricula are too focused on engineering science and technical courses without providing sufficient integration of these topics or relating them to industrial practice. Programs are content driven.
- Current programs do not provide sufficient design experiences to students.
- Graduates still lack communication skills and teamwork experience and programs need to incorporate more opportunities for students to develop these and other competencies.
- Programs need to develop more awareness amongst students of the social, environmental, economic and legal issues that are part of the reality of modern engineering practice.
- Academic staff lack practical experience, hence are not able to adequately relate theory to practice or provide design experiences. Present promotion systems reward research activities and not practical experience or teaching expertise.
- The existing teaching and learning strategies or culture in engineering programs is outdated and needs to become more student-centred.

Beyond these gaps, focused, mainly, in curricula and programs, there another causes for the disconnected world of EE and EPP. This motivated the paper authors to design a cause-effect diagram to discover the causes for this unconnected. This was put in practice during a conference in an Engineering Education theme two years ago, where the authors of this paper asked informally to some participants to fill the diagram on what they believe were the causes for the disconnected between EE and EPP. The result is presented in Fig. 1. Six main causes were identified: faculty, culture/governance (administration), industry, learning methodologies, student, and contextual issues.

methodologies, student and contextual issues. It was evident from the many sub-causes related to the faculty that is in its “hands” to change and provide a fitter education to future engineers. This is possible but demands new Engineering Education paradigms and flatter organizations that allow them to walk the path with society demands. Beyond this, it is necessary a collaboration with industry that can help to define profile of the graduated student, identifying the skills and competencies that a student must possess to be successful on the job. Industry can also provide students with real life projects mentored by industry and provide both students and faculty with internship opportunities in a real life engineering setting as stated by Morell [48].

B. Demands for new educational methods and strategies to link university and industry

Challenges for Engineering Education discussed in section IIA of this paper resulted from the rapid technological advances demanded by a consumer society and a globalized resources market. Although academy is seen as pioneer in research, many times, is one step back to the industry because of its heavy bureaucracy and infra-structures that prevents it to move forward and follow the rapid change occurring. Additionally, the financial and economic crises lived in the “old continent” with impact for all over the world demands moral values and attitudes thinking in the whole, not only in a part, interacting with all stakeholders, not only with shareholders. These could be extended to the needs identified by King [49] to restructure EE. Moreover, three competences had been systematically pointed out by all stakeholders (student, industry and faculty) as missing in the engineers curricula. For example, from a survey about Mechanical Engineering Education to publish ASME Vision 2030 [28], papers authors, after a detailed analysis of the results, revealed competences missing in the engineers graduates by employers: systems, sustainability and ethics competency, but also by students and faculty, with different importance for each. The consequence of this absence is a desynchronized education that results in poor performance and inadaptability of young engineers in the market and workplace.

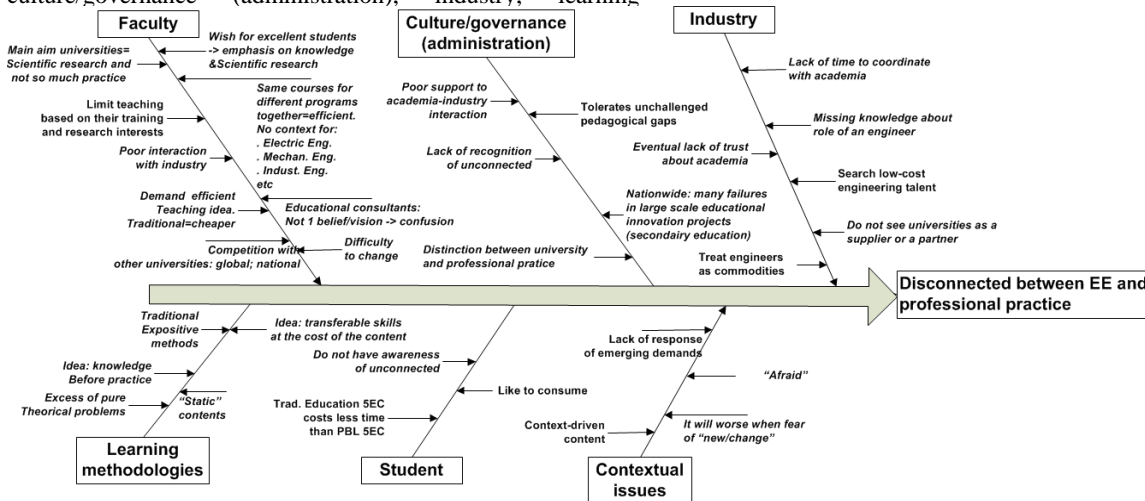


Fig. 1. Cause-effect diagram with the causes for the unconnected of Engineering Education and professional practice.

Challenges for EE presented before and competences needed for new engineers described above, demands new educational methods and strategies to engage students in their own learning and link them to industry environment. Some initiatives for all over the world are happening in the universities through a long reform process at a region scale, e.g. Bologna process in Europe [50], or through others initiatives in different regions [51][52]. Despite these efforts, some universities are slower to change and to engage all faculty in active and student-centred learning methodologies that provide better educational methods [21][47][53][54] and strategies than the traditional lectured and teacher-centred methodologies. Fortunately, sometimes it is only needed a small teachers team that believe on this and implement such learning methodologies [55][56][57]. These learning methodologies also provide appropriate methods, e.g., projects, to link EE to industry. Examples of successful education programs that used projects or Project-Based Learning (PBL) are presented in Lima et al. [58] and Aggarwal [59].

C. Lean Engineering Education definition and principles

The gaps between EE and EPP call for new educational methods and strategies. Some efforts have been made as presented in the previous section but not yet with the expected results. So, the authors believe that a new and innovative way needs to be in practice. Such innovative way is the Lean Engineering Education that was defined [60] as: “A systematic, student-centred and value-enhanced approach to educational service delivery that enables students to holistically meet, lead and shape industrial, individual and societal needs by integrating comprehension, appreciation and application of tools and concepts of engineering fundamentals and professional practice through principles based on respect for people and the environment and continuous improvement.” This definition is the basis for designing the curriculum, teaching and learning, and assessing student progress in the engineering classroom. From an incremental and analytic building process of continuous improvement through Toyota Education Model development, the authors see Lean as a body of knowledge that provides a framework for Lean Thinking to emerge. Lean Thinking principles are translated to the educational services as described:

1) *Value* – identify what is the value for the client. First, it is necessary to define the client. In this case, clients are engineering student, the engineering employer or, in a more global view, the society and faculty. The engineering students pay tuition to receive a value in the form of an education. The employer hires the engineering student to benefit from the value added to the products designed and built to a consumer society. Faculty must provide engineering education services of quality and supply the right needs of society and employers at a reduced cost and time.

2) *Value Stream* – identify the activities that adds value to the products. This means to organize the programs in a way that only valued activities are processed. Clients did not pay waste activities, so engineering student want an education that serves perfectly the employer and society needs, with faculty collaboration and engagement that care for them.

3) *Continuous flow* – continuous flow means a smooth and levelled workload without waste pushing back the students, faculty and society.

4) *Pull system* – this means that is the client that trigger the services delivery and content. So, needs from student engineering, faculty and society must be addressed. It was possible to see above that three competences are systematically referred: systems, sustainability and ethics competencies. Seeing the whole, and not only a part, using problem-solving tools and system thinking are skills needed in the systems engineering [61]. Sustainability competency demands knowledge of sustainability characteristics and principles and to domain some tools like Life cycle analysis among others [62]. Ethics competency is an expected behavior of the engineering profession and is normally supported by a body of knowledge (standards, fundamental canons and behavior descriptions). But, more than knowing, must be practiced [63] and LEE through respect for people from Toyota Education Model is a platform to achieve this [64]. These three competences are the dorsal spine of the value stream that adds value to the delivery of the engineering education.

5) *Pursuit perfection* – means to continuously be unsatisfied with the status-quo and search continuous improvement, i.e., eliminating wastes of all types.

LEE offer benefits for the academy that include the improvement of course design/delivery based on PBL and for the improvement of the overall quality of the learning experience based on student-centeredness. By doing this, it bridges the gaps between academy and industry providing a better student’s preparation for the challenges of the professional profile [65]. This is shared by others authors that had been applied Lean Thinking bodies of knowledge [66][67][68][69][70].

IV. CONCLUDING REMARKS

LEE was presented as a bridging-the-gap innovative educational model. It emerges from the Toyota Education Model responsible for spread the TPS by all factories of the company. Companies all over the world are implementing this model. This is a reason for the authors to believe that are in the right way appointing this as a model to educate young engineers and smooth the entry of engineers in the workplace.

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