Project-Oriented Problem-Based Learning for an Entrepreneurial Vision in Engineering Education

Javier Machado-Toledo, Carlos Efrén Mora(✉), Beatriz Añorbe-Díaz, Antonio González-Marrero, and Jorge Martín-Gutiérrez

Universidad de La Laguna, Calle Molinos de Agua, S/N, La Laguna, Spain
{jmachado,carmora}@ull.edu.es

Abstract. World challenges require engineers to assume risks and leave their comfort zones. Thus, engineering education should empower the students at realising changes that may have a positive impact. This changing mentality engages with business and entrepreneurial ability, so future engineers may be able to turn their vision into real actions to have a true impact. However, this requires the students to apply knowledge, skills, tools and techniques in projects aimed to solve problems, which must be relevant to science or society. Nevertheless, the application of these aspects is not straightforward, and it requires education and experience. Students should be able to find creative solutions to complex problems, and they also should realise that finding such solutions requires team-work, multidisciplinary approaches, reflection, and sustainable financial resources. Project-Oriented Problem-Based Learning (PoPBL) has become one of the most used student-centered learning strategies in engineering education. PoPBL requires students to use their knowledge, skills, and strategies to solve ill-structured problems by team-work projects. This approach links the needs of today's engineering approaches and engineering education. It empowers students to learn through experience, but improving students' entrepreneurial vision requires a perspective of the project management process to make it successful. For this reason, the problem-solving process has to consider aspects like problem analysis, proper planning, risk assessment, financial analysis, and process analysis. Students should assess these aspects through appropriate project-managing tools, so they have a wider vision of the real-world possibilities of their project. PoPBL can include these strategies as part of the learning process. This paper deepens into these aspects, and it tries to put into perspective how entrepreneurial approaches in engineering education can be the base of a positive change for today's problems.

Keywords: Engineering education · Problem-Based Learning
Entrepreneurial education

P. Zaphiris and A. Ioannou (Eds.): LCT 2018, LNCS 10925, pp. 483–491, 2018.
https://doi.org/10.1007/978-3-319-91152-6_37

1 Introduction

The Millenium Project shows 15 areas which describe the global challenges for Humanity: *sustainable development and climate change, clean water, population and resources, democratisation, global foresight and decision making, global convergence of IT, rich-poor gap, health issues, education and learning, peace and conflict, status of women, transnational organised crime, energy, science and technology, and global ethics* [33]. Entrepreneurship and innovation are required to face these challenges, and entrepreneurship education can be a changing agent for our society [34].

In addition, engineering should contribute with urgency to solve these problems in the future decades [28]. But the requirements of engineers to solve 21st century challenges are well above of just being analytical and technically focussed. Modern engineers should be *global engineers*, persons who are technically competent, culturally aware, with an entrepreneurial spirit, innovative and lifelong learners, able to understand market behaviour, nimble, flexible, and mobile [7]. Educating global engineers requires breaking the boundaries of formal engineering education. From a professional perspective, engineering curriculum should include practice-oriented aspects such as design and synthesis, innovation, project and technology management, systems analysis, entrepreneurship, and leadership and professional ethics [10]. This has prompted an increasing shift of the understanding of engineering education, and entrepreneurship education is being introduced to engineering students [11].

In the United States, ex-president Obama has prioritised STEM education and entrepreneurship throughout the next decade [20,23]. In Europe the European Society has emphasized the importance of developing attitudes towards creativity, innovation and entrepreneurship in engineering education [13]. This is also emphasized by other relevant european institutions [1,5,15]. Other countries have also prioritized the introduction of entrepreneurship. In Malaysia, the Ministry of Education has required to produce graduates with entrepreneurial skills who create jobs, rather than just looking for jobs [17].

Therefore, infusing entrepreneurship in engineering education seems to be a priority to policiy-makers and educational stakeholders in different countries. Infusing this entrepreneurial vision requires soft skills [31], which can be supported by problem-based learning (PBL), given that it shares many aspects of the needs of entrepreneurship education, like interdisciplinary, experimentation and problem solving [25,27].

This paper is focussed on how newer educative approaches like PBL are used to strength the set of skills of engineering students required for entrepreneurship.

2 Strategies for an Entrepreneurial Vision in Engineering Education

2.1 Variations of the Strategy to Infuse Entrepreneurship

Traditionally, entrepreneurship education was given only to *business* students. However, the idea that infusing entrepreneurial skills benefits any student was

spread since the end of 20th century. In addition, globalisation and the expansion of ITs increased the interest of students to be entrepreneurs [32].

The analysis of Standish-Kuon & Rice highlight several aspects that may influence the successful introduction of entrepreneurship in engineering education [30]: *Internal and external support* —infusing entrepreneurship requires the support of institutional decision-makers, administrative and academic staff, students, and external companies—, *quality courses*, *financial support*, and *qualified academic staff*. The adopted strategy for an entrepreneurial vision of engineering programs requires a previous analysis of those aspects.

Integrating innovation and entrepreneurship in engineering education requires the academic staff to participate in developing the curriculum, or at least, accept those changes. Nevertheless, it is usual that entrepreneurship courses are given by external staff [6], and this aspect leads to many different approaches to entrepreneurship courses. In addition to this, the complex connections between students, educators, educational processes, and other involved stakeholders, hinder the standardisation of entrepreneurship education [12].

Streeter, Jaquette and Hovies define two approaches of entrepreneurship education at universities: *focused* and *university-wide* [32]. An academic program is focused when students and academic staff belong exclusively to business or business-engineering environments. Having entrepreneurship classes seems to be a requirement for a focussed program. The universities of Columbia, Duke, Harvard and Maryland have examples of focussed programs. In contrast, university-wide institutions, like MIT and Stanford, extend entrepreneurship education to all students. However, university-wide approaches are implemented differently depending on where the teaching of entrepreneurship occurs. For instante, some institutions like MIT concentrate all entrepreneurship courses in one specialised college, which can be attended by students from any degree. Other institutions have courses spread throughout the university, so the teaching of entrepreneurship is more diffused. The choice of any of those systems depends on multiple factors, like funding, administrative facilities, faculty, teaching activities, students, research, outreach, and alumni. However, even when an institution may not have the resources to introduce specialised entrepreneurship courses in its engineering programs, entrepreneurship can be incorporated to the culture of the academic staff [17].

2.2 Some Examples of Innovation in Engineering Education to Infuse Entrepreneurship

Some universities have already embraced student-centered learning strategies with an interdisciplinar spirit. For example, Aalborg University (Denmark) has integrated both concepts of entrepreneurship and engineering in a *Entrepreneurial Engineering* masters degree program by using problem based project work [2]. Northeastern University (USA) developed a similar interdisciplinary entrepreneurship concept and offers an *Entrepreneurial Engineering Minor* program [3]. Other universities are adopting active learning to introduce entrepreneurship in their engineering programs, like the University of Minho [29].

3 Skills and Requirements for an Entrepreneurial Vision of Engineering Education

Today's engineers require not just being technically and analytically proficient, but also creative, team-workers, efficient communicators, resilient, empathetic, and able to take opportunities [6,31]. Engineering education has to contemplate these skills to make students being more innovative and entrepreneurial [6]. This pushes universities to educate engineers to be able to find innovative and creative solutions to real-world problems from an entrepreneurial perspective. Developing these skills contributes positively to the development of entrepreneurial attitudes of engineering students [29].

Entrepreneurial skills are diverse and transversal to engineering practice. Thus, these skills —or soft skills— are those required to enable the full potential of graduates in the real world [31], e.g.: innovative behaviour, negotiation abilities, leadership, creative thinking [22]; cross-functional thinking, ambiguity tolerance [27]; planning, problem-solving, communication, critical thinking, leadership, negotiation, social networking, team-working, time-managing, decision-making [35]; internal locus of control, optimism, commitment, and risk-taking [36].

But it is not enough to introduce entrepreneurial skills in the curriculum. Entrepreneurial skills are improved when learning is based on experience [36] through doing and reflection [25]. Pittaway defined 6 requirements when simulating entrepreneurial learning [25] to stimulate entrepreneurship:

1. *Uncertainty and ambiguity* through unfamiliar activities and projects, group dynamics and linking the students' academic performance to their project's performance.
2. *Action orientation and proactive behaviour* through project-based and experiential approaches.
3. *Discontinuities, events, crisis, and failure* through regular milestones and challenging goals.
4. *Mentoring* through tutors to challenge thinking.
5. *Socially situated learning* through self selection of their venture team members and the using of learning coaches and venture panels at the end of the course.
6. *Constant learning* through using established knowledge to new problems.

4 How Project-Oriented Problem-Based Learning Supports Entrepreneurial Skills

4.1 Description of the Problem-Solving Process

Basically, Problem-Based Learning (PBL) consists in exposing students to ill-structured real-world problems. This problem does not have a unique solution so it requires knowledge, skills and a strategy to reach a satisfactory solution. PBL is also the acronym of Project-Based Learning, which leads to the delivery of a product —a design, or a physical or simulated model—, which outcome is

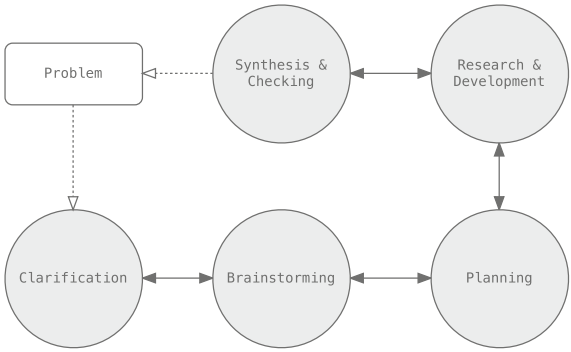

Fig. 1. Problem solving process in PoPBL

summarised with a report (project) [26]. Both strategies share the same principles of learning [9]. If fact, Barrows considered Problem-Based learning as a set of multiple alternatives for a chosen learning goal [4].

Project-Oriented Problem-Based Learning (PoPBL) consists in an hybrid practice: students are firstly exposed to a real-world problem and then develop a project to solve it. Because of the nature of this process, the project is open ended and it is structured as in a pure problem-based approach [26]. Thus, students follow a problem-solving process which can be explained in 5 steps (Fig. 1) [21]:

- *Clarification:* Students clarify the problem and trigger previous knowledge.
- *Brainstorming:* Students discuss how to solve the problem.
- *Planning:* Students plan their activities for their project, including gaining new knowledge.
- *Research & Development:* Students research to gain knowledge and develop their project.
- *Synthesis & Checking:* Students check their solution, synthesize their findings, and fill their gaps.

4.2 PBL Cornerstones for Entrepreneurship

To be aligned with an entrepreneurial vision the whole PoPBL process has to be sustained by 3 cornerstones:

- *The problem* (Fig. 2): Has to be relevant socially, scientifically or technically. It also has to be complex, it will require multiple disciplines and will have multiple solutions.
- *The problem-solving process* (Fig. 3): It will require a holistic, multidisciplinar, and creative approach. In addition, it will integrate previous knowledge, and will contemplate the acquisition of new knowledge. Finally, the process has to include analysis by communication and reflexion.

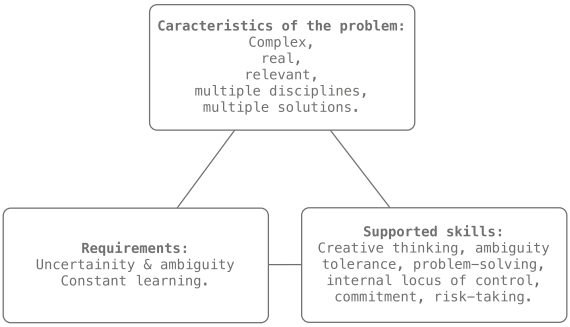

Fig. 2. Problem, requirements and supported skills

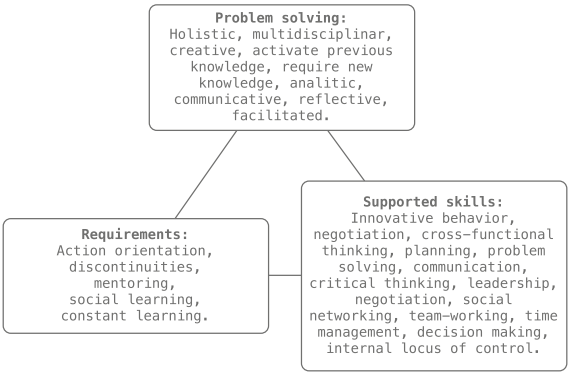

Fig. 3. Problem solving, requirements and supported skills

– *The solution* (Fig. 4): It will require any deliverable (project). The solution must be economically, socially, and environmentally sustainable. In addition, the solution has to be attractive to the market.

4.3 Developing of Project Management Skills Through PBL

Project management skills are related to entrepreneurship. In fact, profitability and creativity are linked with the acquisition of entrepreneurship skills [19,24]. In addition, its been recognised the importance of acquiring soft skills when students learn project management at universities [24].

PBL eases the acquisition of soft skills and project managing skills [18]. When students develop their projects, they develop project management skills [8]. However, it is usual that students do not have previous knowledge and hard skills about project management when exposed to PBL for the first time. In this regard, it is important support the students properly to get them engaged and motivated [21]. If possible, including project management workshops within the problem-solving

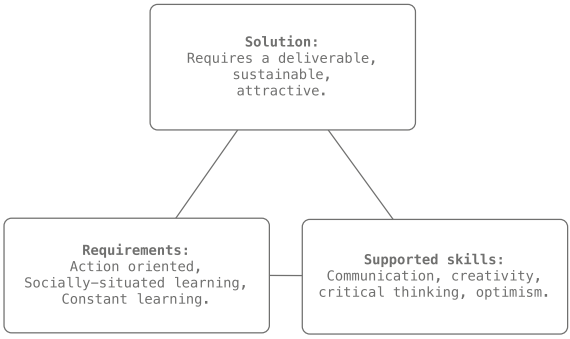

Fig. 4. Solution, requirements and supported skills

process will help students to learn about project management. However, students should perceive that any additional learning has to be useful [16], so workshops and/or other materials should be given when facilitators understand they are necessary, or students require those contents. Hence, each step of the problem-solving process has to boost different aspects of project management on students. Furthermore, those contents have to be selected and adapted to the previous knowledge and skills of students. As an example, the following list, but non-exhaustive, suggests some workshops to enhance project management skills of freshmen students enrolled in an undergraduate engineering degree:

- *Clarification:* Icebreaking activities. Problem formulation. Problem solving process.
- *Brainstorming:* Techniques for effective brainstorming.
- *Planning:* Project planning. Conflict management. Teamwork apps.
- *Research & Development:* Effective teamwork. Technical and scientific writing. Process Analysis.
- *Synthesis & Checking:* Project evaluation and analysis. Project presentations. Oral communication.

5 Conclusion

It is accepted that infusing entrepreneurial skills in engineering education will contribute for a positive change. More creative entrepreneurs graduates will contribute to create more jobs [14] and more creative engineers will find better solutions for today's challenges. The mix of engineering and entrepreneurship makes sense.

These skills are not innate, but can be learned through experience [36]. When students try to solve complex problems they trigger their previous knowledge, but also require learning new knowledge and skills to develop their solution.

Even if engineering students can not follow specific entrepreneurial courses, active learning eases the acquisition of entrepreneurial skills. In addition, the cornerstones of the PoPBL process —the problem, the problem-solving process, and the solution— are linked to the acquisition of entrepreneurial and engineering

soft and hard skills. Those skills constitute the scaffolding required by students to further understand entrepreneurship and being able to contribute for a positive change.

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