JEDIC Journal of Ethics and Diversity in International Communication

| e-ISSN: 2792-4017 | www.openaccessjournals.eu | Volume: 2 Issue: 7

Methodology of Forming Engineering Competencies in Students Based on Innovative Approach. (In the Example of the Educational Direction of Construction and Technology of Light Industrial Products (Sewing Products)

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Annotation: This study discusses innovation competences development in these courses with the aim of understanding how to better design educational strategies to improve them. Through content analysis, we compare the outcomes of two groups of Telecom Engineering students undergoing a capstone course following a classical product development project approach and a challenge-based course using Design Thinking. Results show that both course types contribute to developing innovation competences. Nevertheless, depending on the chosen pedagogy some competences are developed further.

Keywords: Project based learning; challenge-based education; innovation competences; Design Thinking; multidisciplinary education.

Over the past two decades, there has been a growing discussion about the gap between industry needs and the competences of engineering graduates (Dym et al. 2005). Engineering graduates are perceived to be ‘too theoretical’ by the industry and face difficulties when adapting to the practical working context. Traditionally, the education of an engineer has started by laying a solid foundation in science and mathematics, and specific engineering subjects are taught only after this theoretical foundation has been established (Dym et al. 2005). This approach for engineering pedagogy contributes to the gap between industry needs and engineering graduates’ competences. Furthermore, the expected competences of future engineers go beyond the purely technical skills. Competences like creativity, innovativeness, business skills, sense of responsibility, problem-based thinking, collaboration, ability to communicate and effectively dealing with stress and uncertainty, among others, will be increasingly important in the future (Pippola et al. 2012). Also ABET (Accreditation Board for Engineering and Technology 2017) and NAE (National Academy of Engineering 2004) in the United States and ENAEE – EUR-ACE® (European Network for Accreditation of Engineering Education 2020) in Europe, emphasise these competences for future engineer graduates. An education that remains only in the scope of technical skills traditionally expected from engineers will eventually limit their capabilities to influence strategy and management decisions, as well as concept definition for new products and services (Leitch, Dittfurth, and Davis 2011). Ultimately, the more engineers master the innovation process beyond the technical aspects, the more impact they can have in shaping the society of the future, and the greater chances they have to position themselves as decision-makers. Existing research shows that experiential learning approaches like project-based and challengebased education are good educational strategies to develop innovation competences. Although, it is not found in literature and thus, a deeper analysis is needed to understand which approach is better to develop the aforementioned innovation competences in engineering education. Also, there is not a clear definition of what are the innovation competences required for engineering graduates. All this led

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us to define our research questions as: which are the innovation competences needed for future engineers and what are the best experiential learning strategies to develop them in engineering students? To answer our research questions, we first developed a literature review to understand which innovation competences are required for engineering graduates. Then we selected two of the experiential learning courses taken by University of Catalonia (UPC) Telecom engineering students, a product development project (PDP) course and a challenge-based course and compared the results regarding these competences. In an initial hypothesis, it was expected that the challenge based course would notably surpass the PDP course in almost all innovation competences development, especially in Creativity, Leadership & Entrepreneurship, Teamwork, and Impact, as it is a course focused on innovation, while the PDP course is focused more on engineering design and implementation. In the following sections, we discuss existing innovation competences models and pedagogical approaches to develop those competences. We then define a combination of these existing innovation competences models into a framework used for analysing and comparing the results of the two experiential learning approaches and we discuss conclusions and recommendations for developing educational strategies to develop innovation competences in engineering education. Innovative behaviours may be learnt, and this learning should be based on experience and experimentation incorporating real-world experiences into the engineering curriculum (Chell and Athayde 2009; Shuman, Besterfield-Sacre, and McGourty 2005). Thus, innovators may be developed with an appropriate education strategy, training, and experience. Innovation pedagogy is a learning approach that describes in a new way how students assimilate, produce, and use knowledge in a way that can create innovations (Kairisto-Mertanen, Penttilä, and Putkonen 2010). The main idea of applying an innovation pedagogy is to 'bridge the gap between the educational context and working life', which can be achieved through learning using active multidisciplinary methods. The core of this pedagogy lies in reinforcing an interactive dialogue between the educational institution, students, real working life, and society. Its learning outcomes are the knowledge, skills, and attitudes (competences) required for innovation projects to be successful (Kairisto-Mertanen et al. 2012). To identify the innovation competences required for engineering graduates, the literature review focused on competences demanded by relevant engineering institutions (ABET, Conceive-Design-Implement-Operate [CDIO], and ENAEE – EUR-ACE®), with emphasis on innovation competences. In addition, the most exhaustive studies in Europe on innovation competences were reviewed: Innovation Competencies Development project (INCODE), Framework for Innovation Competencies Development and Assessment (FINCODA), and National Endowment for Science, Technology and the Arts of United Kingdom (NESTA). INCODE (Watts, García-Carbonell, and Andreu-Andrés 2013, 2014) focuses on higher education, while FINCODA (Marin-Garcia et al. 2016) is meant to be applied in companies or other organisations. FINCODA was created as a new innovation competence model that complements and extends the existing ones (previously analysing more than 12 innovation competence models). NESTA developed a set of innovation competences and a tool to measure them after a broad literature review and extensive testing in the UK (Chell and Athayde 2009). Table 1 presents a summary of the identified innovation competences considered the most relevant ones for this research. Creativity, Critical Thinking, Network, Impact, and Leadership competences are consistently mentioned in the different innovation competences' studies. In the case of engineering competences literature, the most relevant ones identified related with innovation are Investigation and Knowledge Discovery, Experimentation, Engineering Entrepreneurship, Engineering Practice, Communication & Teamworking. In general, it was found that competences listed by ABET, CDIO and ENAEE – EUR-ACE® do not explicitly talk about innovation competences, although there are many of them that are clearly related to innovation. In these cases,

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where competences are not specifically branded as innovation competences, the selection was made identifying the ones related to innovation within their definitions on a first or second level, by analogy, and/or similarity with the innovation competences explicitly defined by INCODE, FINCODA, and NESTA.

Once identified the innovation competences for engineering graduates and the two suitable and prevalent learning approaches for developing them, we aimed to analyse, identify, and compare the engineering students' innovation competences acquired in two different types of experiential learning courses: a project-based and challenge-based combined with Design Thinking. We analysed two courses developed at ICT engineering at Technical UPC: PDP course and the CBI course (Challenge-Based Innovation [CBI]). PDP is a mandatory project-based course developed since 2012, within the CDIO (Conceive Design-Implement-Operate) framework that follows the classical product development process described by Ulrich and Eppinger (2008) to solve a technical challenge posed by a company or institution. The ICT engineering degree curricula at UPC was re-designed according to the EHEA directives using the CDIO Standards (Bragós et al. 2010). Three project-based design-implement courses were inserted in the second, third, and fourth year of the Telecom engineering bachelor. The PDP capstone project (named Advanced Engineering Project [AEP]) is placed in the fourth year. Students from the different minors of the Telecom Engineering degree (Electronics, Networks, Audiovisual Systems, and Communication Systems) are arranged in mixed teams to tackle a complex technical problem defined by a company, NGO, hospital, or external institution. The students should design, build, and test the different blocks of the project and finally integrate and test a proof-ofconcept functional prototype. They should also define a business model. The school asks the external institutions to present challenges with a complex solution, so the teams, which are intentionally big, are forced to split in parallel work packages and have to manage the subprojects and the system integration, resulting in a functional prototype. This course can be assimilated to an NPD (New Product Development) course (Fixson 2009). Usually, the starting point is a solution proposal and a set of requirements stated by the external institution. Also, since 2014 students can opt to take CBI (as an alternative to PDP), a course with a challenge based learning approach (Malmqvist, Rådberg, and Lundqvist 2015) combined with Design Thinking methodology (Brown 2008, 2009; Ratcliffe 2009). Challenge-Based Innovation is part of a CERN program that hosts innovative educational projects (Hassi et al. 2016). The course is developed collaboratively by three educational institutions from Barcelona: UPC Telecom (engineering), Istituto Europeo di Design (design), and ESADE Business School (management), in close collaboration with Idea Square at CERN, one of the nodes of the Aalto Design Factory Global Network. Its objective is to design disruptive solutions to complex societal problems following a challenge-based learning approach combined with Design Thinking, considering the use of CERN technologies if suitable. In multidisciplinary teams (engineering, business and design), the students develop a solution (after an in-depth user and market research) including product and/or service, a business model, and a proof-of-concept prototype, with three periods at CERN during the project and a final gala presentation in front of authorities, professors, and press (Charosky et al. 2018). In the first editions, the challenges were defined by collaborating companies, institutions, or NGOs, and since 2017 the challenges are defined within the United Nations – Sustainable Development Goals.

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