Developing innovation competences in engineering education through project-based and challenge-based learning

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PhD program in Business Administration and Management

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Abstract

There is a gap between industry needs and engineering graduates' competences that since the past two decades has been under discussion. Engineering graduates are perceived as "too theoretical" by the industry and face difficulties when adapting to the practical working context. This gap is being mostly tackled by project-based courses. Furthermore, the expected competences of the 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. Innovation competences in particular are key to tackle current societal challenges, but there is limited understanding about what innovation competences are developed through different types of project-based courses.

An education that remains only in the scope of technical skills traditionally expected from engineers will eventually limit the capabilities of the engineers to influence strategy and management decisions, as well as concept definition for new products and services. Institutions like ABET, CDIO and ENAEE – EUR-ACE®, highlight these demands for future engineers' competences. 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.

This study discusses what are the innovation competences needed for engineering students and pedagogical approaches to develop those competences, with the aim of understanding how to better design educational strategies to improve innovation competences in future engineering graduates.

A broad literature review was developed on existing innovation competences models and pedagogical approaches to develop innovation competences, going from problem-based to project-based learning to challenge-based education, from New Product Development to Design Thinking, and through different strategies to measure innovation competences.

Through a mixed method approach, combining quantitative analysis of surveys and qualitative content analysis of project results, we compared two experiential learning courses developed at the UPC Telecom school: a project-based course and a challenge-based course.

We compared self-perception on innovation competences using the INCODE (Innovation Competences Development) Barometer and we developed a qualitative content analysis of project results and self-reflection documents of two groups of engineering students from Telecom Engineering school from UPC going through CBI (Challenge Based Innovation) course versus PDP (Product Development Project) course. CBI is an innovative learning experience carried out by three institutions: Telecom Engineering School of UPC, ESADE Business School and IED Istituto Europeo di Design in collaboration with CERN, where mixed teams of students from the three institutions face open innovation challenges through Design Thinking, with the objective of designing solutions to complex societal problems, considering the use of CERN technologies if suitable. PDP is the "standard" capstone course taken by Telecom engineering students following a classical project management approach based on the CDIO framework.

Results shows that experiential learning approaches like project-based and challenge-based education are good educational strategies for developing competences and, explicitly, innovation competences in engineering education, but each strategy emphasizes some competences more than others. Project-based courses demonstrates better results in Planning and Managing Projects. Creativity, Leadership and Entrepreneurship are more developed through a challenge-based approach combined with Design Thinking.

Keywords: *Innovation, Innovation competences, Project-Based Learning, Challenge-based Education, Design Thinking, Multidisciplinary Education*

Preface

As an Industrial Designer graduated at the University of Buenos Aires in 2003, I have always had an interest in innovation (creating new things, technology, creativity...) as well as in education, being an ad-honorem teaching assistant at my home university in the early years of my career. After graduating, I started my PhD at the Technical University of Catalonia (UPC) in 2005 in the program "Innovation projects in product and process engineering". I presented my Thesis Project in 2007, obtaining the Advanced Research Diploma. On the same year I have also acquired a Postgraduate in Business Management from the Industrial Organization School.

In 2007, for professional reasons I decided to put my PhD on hold and dedicated to work on the field of design and innovation, both in-house (at HP) and in consultancy, as well as a projects professor at the Istituto Europeo di Design (IED).

I am currently the co-founder and director of the innovation & design consultancy Drop, based in Barcelona. I am academic collaborator at ESADE Business School, where I teach Design Thinking, Lean Startup and Innovation in the Executive MBA and I am also the Director of the Innovation Lab at the MBA. I am also the Coordinator of the Masters in Strategic Design, Innovation & Entrepreneurship at IED (Istituto Europeo di Design). My professional life is a mix of innovation practice and innovation education.

As a professor of Istituto Europeo di Design (IED), I have participated from 2014 to 2019 of an innovative learning experience that has been carried out by three institutions located in Barcelona: Istituto Europeo di Design (IED), ESADE Business School and UPC-Telecom BCN. Design, management and ICT engineering students are mixed together in multidisciplinary teams to face a societal challenge along a semester. The framework of these projects is the Challenge Based Innovation (CBI) program, a structure promoted by CERN in which students from different disciplines and countries are challenged to design solutions to societal challenges following the Design Thinking approach.

This educational project revived my interest in research, and I decided to refocus my PhD into education for innovation, as this opportunity created the perfect ground for designing a research project focusing on engineering students participating in this learning experience.

We have observed that within the framework of multidisciplinary projects and challenge-based education, using Design Thinking as a methodology, students' (in particular engineering students) competences in innovation and self-confidence can be highly improved. Initially, these observations were informally collected through some surveys, without a structured process and a clear research objective. And in 2017, I decided to formalize it into a PhD research.

The purpose of this work is to contribute to innovation competences development in future professionals, a fundamental aspect of education nowadays. With the huge challenges we are facing as a society today and in the near future, we need professionals that not only understand but master the innovation process, as the challenges we need to solve as humans (climate change, global warming, access to water, poverty...) cannot be solved with "traditional" formulas. This requires a different approach and a holistic understanding of both people and society's needs, technology and business.

This thesis is the result of 4 years of research dedicated to understanding through literature review which are the innovation competences to be developed, how to measure them and different pedagogies to develop these innovation competences. After setting up this framework and summarizing the existing knowledge, it was developed an experiment to understand how two different experiential learning experiences (project-based and challenge-based) contribute to developing innovation competences in ICT students.

The objective of this work is to contribute to better design educational strategies that foster innovation competences in engineering students, extending also the conclusions to other disciplines, as innovation competences are transversal and not exclusive for engineers.

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To Alessandro Manetti and Luciana Leveratto, from IED, I am thankful for thinking of me as a professor and coach for CBI in representation of IED. If it wasn't for them giving me this opportunity, nothing of this would have happened.

Also, I want to thank my co-founder, friend and partner in crime Pierpaolo Congiu for his continuous support and friendship.

I would like to thank my family: my parents Marta & Eduardo, and brothers Pablo & Michelle for always being there, supporting me in anything I do.

Finally, special thanks to my wife Silvia for her love, support and patience, and my kids, Thiago & Gael for their early morning hugs and their understanding. This work is dedicated to them.

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List of abbreviations and symbols

- ABET: Accreditation Board for Engineering and Technology
- ACOT: Apple Classrooms of Tomorrow
- ACOT2: Apple Classrooms of Tomorrow Today
- CBI: Challenge Based Innovation
- CBL: Challenge Based Learning
- CDIO: Conceive-Design-Implement-Operate
- CDR: Critical Design Review
- CERN: Conseil européen pour la recherche nucléaire / European Organizationfor Nuclear Research
- DF: Design Factory
- DFGN: Design Factory Global Network
- DT: Design Thinking
- EC2000: Engineering Criteria 2000
- EHEA: European Higher Education Area
- ENAEE: European Network for Accreditation of Engineering Education
- ETSEIB: Escola Tècnica Superior d'Enginyeria Industrial de Barcelona
- ETSETB: Escola Tècnica Superior d'Enginyeria de Telecomunicació de Barcelona
- FDR: Final Review Meeting
- FINCODA - Framework for Innovation Competencies Development and Assessment
- ICE: Science Education Institute
- ICT: Information and Communication Technologies
- IED: Istituto Europeo di Design
- INCODE: Innovation Competences Development
- KIA: Kirton’s innovation-adaptation
- MBA: Master in Business Administration
- MIT: Massachusetts Institute of Technology
- NAE: National Academy of Engineering
- NESTA: National Endowment for Science, Technology and the Arts
- NGO: non-governmental organization
- NPD: New Product Development
- NPS: Net Promoter Score
- OECD: Organization for Economic Cooperation and Development
- PAE: Advanced Engineering Project
- PBL: Project Based Learning

- PCB: print circuit boards
- PD: Product Development
- PDP: Product Development Project
- PDR: Preliminary Design Review
- PMBOK: Project Management Body of Knowledge
- POPBL: project oriented problem based learning
- R&D: Research & Development
- RDI: Research, Development and Innovation
- SDG: Sustainable Development Goals
- STEM: Science Technology Engineering and Mathematics
- TAEE: Technologies Applied to Electronics Teaching
- UN: United Nations
- UPC: Universitat Politècnica de Catalunya
- UPF: Universitat Pompeu Fabra

Glossary

- **Capstone project:** A capstone course or capstone project is a culminating and integrative experience of an educational program (Ford, 2002), where students apply what they have learnt in other courses into a project. As discussed by Alarcón et al. (2013), capstone projects are considered "to be enablers to engineering activity".

- **CBI Course:** Innovative educational experiences developed collaboratively by UPC Telecom (engineering), Istituto Europeo di Design (design) and ESADE Business School (management), in close collaboration with IdeaSquare at CERN. 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 of engineering, business & design students (Charosky et al., 2021).

- **Challenge Based Innovation:** Challenge Based Innovation (CBI) is a program created by CERN to host educational projects where students from different disciplines working in multidisciplinary teams tackle innovation challenges through Design Thinking, with the objective of designing solutions to complex societal problems (Charosky et al., 2018).

- **Challenge Based Learning:** "a learning experience where the learning takes places through the identification, analysis and design of a solution to a sociotechnical problem. The learning experience is typically multidisciplinary, takes place in an international context and aims to find a collaboratively developed solution, which is environmentally, socially and economically sustainable" (Malmqvist et al., 2015)

- **Design Thinking:** Design thinking is a human-centered approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success (Brown, 2008).

- **Experiential learning:** "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combinations of grasping and transforming the experience" (Kolb, 1984). Effective learning occurs when a person goes through a four stages cycle: of (1) having a concrete experience, (2) observing and reflecting on that experience, that then leads to (3) the construction of abstract concepts (analysis) and generalizations (conclusions) which are then (4) used to test hypothesis in future situations, resulting in new experiences.

- **FINCODA - Framework for Innovation Competencies Development and Assessment :** The FINCODA Innovation Barometer Assessment Tool is a psychometric tool that measures individuals' capacity for innovation, breaking it in 5 areas and assessing capacity of the individual in each of them separately. FINCODA was created as a new innovation competence model that complements and extends the existing ones, considering innovation competence as the group of capacities, skills or behaviors that allow an individual to innovate (Marin-García et al., 2016). There are three dimensions that comprise the FINCODA innovation competence model: creativity, critical thinking and intrapreneurship. This last, being composed by initiative, teamwork and networking.
- **INCODE - Innovation Competences Development:** The INCODE Barometer is a scoring rubric that aims to contribute in developing and assessing innovation competences in higher education contexts (Watts et al., 2013). It covers three dimensions at a competence level: individual, interpersonal and networking following the model proposed by Penttilä and Kairisto-Mertanen (2012) for measuring innovation competences in higher education students. The Barometer can be used in several ways: self-assessment, peer assessment and also by teachers to assess students' learnings outcomes.
- **Innovation competences:** Innovation competences are "the learning outcomes which refer to knowledge, skills and attitudes needed for the innovation activities to be successful" (Kairisto-Mertanen, 2012).

- **Innovation:** The creation of better or more effective products, processes, services, technologies, or ideas that are accepted by markets, governments, and society (OECD, 2005) or as Baregheh et al. (2009) conclude after analyzing 60 definitions of innovation, "is the multi-stage process whereby organizations transform ideas into new/improved products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace."

- **NPS – Net Promoter Score:** The NPS is a tool used to measure the loyalty of customers to a company/brand based on their recommendations. It is an indicator created by Reichheld (2003) and published first in the Harvard Business Review. Since then, it became an industry standard to measure the loyalty or satisfaction of a client with a brand. The Net Promoter Score, better known as NPS is based on asking the question: "On a scale of 0 to 10, how likely are you to recommend this company's product or service to a friend or a colleague?". In this scale of likeliness of recommendation from 0 to 10 according to the results the clients are classified into promoters, passives and detractors.

- **Problem-based learning:** Problem-based is a student-centered pedagogy with an inductive approach, where the students discover the need or application before principles or tools are taught (Felder and Brent, 2004), and in which students learn about a subject through the experience of solving an open-ended problem found in trigger material.
- **Product Development Project (PDP):** PDP is a mandatory project-based capstone project (named Advanced Engineering Project) placed in the fourth year of ICT engineering curricula, within the CDIO (Conceive-Design-Implement-Operate) framework (Crawley et al., 2014). It follows the classical product development process described by Ulrich- Eppinger (2008) to solve a technical challenge posed by a company, NGO, hospital or external institution.

- **Project-based learning:** Project-based learning is "an overall approach to the design of learning environments". It is based on the "constructivist finding that students gain a deeper understanding of material when they actively construct their understanding by working with and using ideas."(Krajcik & Blumenfeld, 2006, Blumenfeld et al., 2000, and Krajcik et al., 1994)

Introduction

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. As an example, Radcliffe (2005) describes the skills and knowledge that engineering innovators should possess, arguing that innovation is an integrative meta-attribute overarching most of the other engineering graduate attributes. 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), CDIO initiative (Conceive-Design-Implement-Operate, Crawley et al., 2011, 2014), NAE (National Academy of Engineering, 2004) and ENAEE – EUR-ACE® (European Network for Accreditation of Engineering Education, 2020), emphasize 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 et al. 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. Also, when speaking about teaching innovation to engineers, as described by Belkhir et al. (2018) the approach should be focused on innovation that "foregrounds societal impact as opposite to technical progress".

Innovation can be defined as the creation of better or more effective products, processes, services, technologies, or ideas that are accepted by markets, governments, and society (OECD, 2005) or as Baregheh et al. (2009) conclude after analyzing 60 definitions of innovation, "is the multi-stage process whereby organizations transform ideas into new/improved products, services or processes, in order to advance, compete and differentiate themselves successfully in their marketplace."

According to Kairisto-Mertanen (2012), innovation competences are "the learning outcomes which refer to knowledge, skills and attitudes needed for the innovation activities to be successful". The same author and also others (Marín-García et al., 2011, Marín-García et al., 2016) identify as the most relevant innovation competences as creativity, creative problem solving, problem identification, independent thinking, openness to new ideas, research focused, teamwork and forward-looking approach. However, there is still much discussion on which are the needed innovation capabilities, and how to measure their acquisition (Marí-Benlloch et al., 2017).

European Higher Education Area (EHEA)'s main aim in the last few years has become developing students' skills to allow them the greatest success in the labor market, through incorporating better academic education processes (Marí-Benlloch et al., 2017). As these authors mention, one of the key aspects of this, is developing transversal skills, which are the capabilities that can be used for any profession. This means that innovation competences are no different from one profession to another. Innovation competences are needed and can be applied in any field, as ultimately, they are a way to tackle complex challenges or problems. In this context, where innovation raises as a source of competitive advantage in the business world, innovation competences are the most determinant aspect of a company performance (Martínez-Gómez et al., 2016, Mone et al., 1998). Both at an organizational level as well at a personal level, innovation is important, thus developing innovation competences in higher education is a must for companies' competitiveness.

The education system needs to prepare future generations with "the skills for innovation to a greater degree than ever before: the confidence and insight to generate a novel idea or new approach; the motivation, commitment and resilience to pursue that idea; the leadership, energy and dynamism to communicate their vision to others and drive it forward from concept to reality". And for these skills to be taught, it is mandatory that we are able to identify and measure them (Chell & Althayde, 2009).

Innovative behaviors may be learnt, and this learning should be based on experience and experimentation incorporating real-world experiences into the engineering curriculum (Chell & Althayde, 2009, Shuman et al., 2005). Thus, innovators may be developed with an appropriate educational 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, et al., 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)

Current research stresses an experiential learning approach (Kolb, 1984), where the participants go through the key stages of innovation, moving from the concrete and abstract worlds (Beckman & Barry, 2007), in an environment with diverse teams to develop these competences. According to Kolb (1984), experiential learning is "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combinations of grasping and transforming the experience." As Fixson (2009) states that "If innovation is understood as a process of inventing and commercializing new products and services, as a process that incorporates activities from multiple disciplines, and as a process that follows more heuristic than algorithmic rules, then perhaps this process can be taught in an interdisciplinary setting with a strong experiential emphasis, such as product design and development".

Within these experiential learning approaches, the 5th standard of the CDIO initiative (Conceive-Design-Implement-Operate, www.cdio.org), states the convenience of including two or more design-implement experiences in the engineering curricula, including one at a basic level and one at an advanced level. Adhered institutions usually have even more than two, concluding in a capstone project in the last year of engineering bachelor. They have evolved from "made up" projects created by faculty members, to product development projects with real industry challenges sponsored by companies or institutions (Dym et al 2005). These types of projects contribute to developing competences like teamwork, problem solving or communication, among others (Sayrol et al., 2015, Bragós et al., 2010).

It could be said that product development project courses have traditionally trained engineers to develop technical solutions rather than to innovate. Following OECD's definition of innovation, engineering student projects tend to be more inventions than innovations, as in general they lack sufficient considerations regarding the implementation of the solution from a value generation and value capture perspective. This contributes to the gap perceived by the industry and highlights the need to create educational strategies to develop innovation competences in engineering students that meet industry needs, but also match those key innovation competences identified by institutions.

Today's systems and problems are progressively larger and more complex, and problems cannot be solved by applying a technical solution alone, as societal, rather than technical issues play a bigger role (Lehman et al., 2008). The challenges the world is facing and will face in the future (globalization, climate change, demographic change, among others) need a different response from our education system (Chell & Althayde, 2009). It is needed to prepare future generations not only with strong basic skills and technological knowledge, but with the ability and attitude, and wider competences to create new solutions, and to adapt to our rapidly changing world. This has shifted (or is shifting) educational strategies from the traditional paradigm with a discipline-oriented, lecture-centric and technical knowledge-based to a new interdisciplinary, student-centric and contextualized, with a complex understanding of technological knowledge. Engineers today need to have skills for interdisciplinary cooperation, communication skills, project management abilities and life-long learning abilities (Lehman et al., 2008). However, getting to this cross-disciplinary and contextual knowledge, integrating comprehension and skills from diverse disciplines is challenging and require innovative ways to approach education.

Challenge-based learning is offered as the model that takes the best of problem-based learning, project-based learning and contextual teaching and learning while focusing on real problems faced in the real world (Johnson et al., 2009). Challenge-based learning, as defined by Malmqvist et al. (2015) is "a learning experience where the learning takes places through the identification, analysis and design of a solution to a sociotechnical problem. The learning experience is typically multidisciplinary, takes place in an international context and aims to find a collaboratively developed solution, which is environmentally, socially and economically sustainable". Challenge-based learning can be seen as an evolution of project-based learning but with a few differences, such as for example starting with large open-ended problems, training of self-awareness and self-leadership and entrepreneurial mind-set. The unique idea of challenge-based learning is that problems are relevant and with global importance, related to sustainability, water, energy, poverty, etc. Also, a differential aspect is the "call to action" that goes beyond the classroom, inviting the students to have an impact on the society with their projects (Malmqvist es al., 2015).

Working with open-ended problems in a more dynamic process (compared to design-build-test projects), shifting the focus from a technical problem to a societal problem, and requiring multidisciplinary knowledge poses challenges both for faculty and students involved in challenge-based learning. This approach raises the level of ambition of engineering education, going beyond the technical arena into the socio-technical domain developing competences like multidisciplinary teamwork, decision-making, communication and leadership (Malmqvist es al., 2015).

Friedman (2019) suggests a list of challenges for design education, stating that "These challenges create a new context for the design process. Some forms of design remain similar to what they have long been. Other forms of design emerge in response to new developments, new tools, new situations, and new technologies." These challenges can be perfectly applied to engineering education, as what designers design, then engineers would be needed to implement.

These challenges defined by Friedman (2019) are divided in four groups and are cumulative, meaning that each group depends upon the abilities, knowledge, and requirements of the previous one.

- Performance Challenges: related to what designers (or engineers) have to do, rather than a challenge to their skill sets.
- Systemic Challenges: related to addressing entire systems, rather than just a single part.
- Contextual Challenges: related to dealing with complex systems that are strongly influenced by their environment, local culture, and political issues.
- Global Challenges: related to dealing with complex sociotechnical systems.

As discussed by Meyer & Norman (2020), the question is How do we train people to become capable of working within these groups of challenges? Today, most design and engineering education addresses only the first group (Performance Challenges) or the second (Systemic Challenges) but very few cover Global Challenges. Thus, there is a need to train future graduates to develop innovation competences to tackle these challenges.

Design Thinking has been widely recognized for effectively dealing with the high levels of uncertainty involved in challenge-based projects. It is defined by Tim Brown (2008) as "a human-centred approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success". This innovation approach emphasizes people behaviors observation for detecting needs, multidisciplinary teamwork, quick and early visualization and prototyping of concepts to test them iteratively during the process. Design Thinking is for innovation early stages (Carr et al., 2010) and does not replace professional design or engineering (Charosky et al., 2018). It complements and reinforces the initial phases of innovation.

Research shows that experiential learning approaches like project-based and challenge-based education are potentially 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, as stated above there is not a clear definition of what are the innovation competences required for engineering graduates.

All this led 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, as research framework we selected two of the experiential learning courses taken by UPC Telecom engineering students, a product development project (PDP) course and a challenge-based course and compared the results regarding these competences.

The first part of the literature review was aimed at identifying innovation competences required for future engineering graduates and how to measure these competences. Relevant engineering institutions like ABET – Accreditation Board of Engineering and Technology (2017), CDIO - Conceive Design Implement Operate - initiative (Crawley et al., 2011, 2014), ENAEE – European Network for Accreditation of Engineering Education (2020), Spanish Ministry of Science and Innovation (competences for ICT engineering students, 2009) and Technical University of Catalonia-UPC (Bragós et al., 2010) listed competences were analyzed. Also, publications from reference innovation institutions like NESTAformerly, National Endowment for Science, Technology and the Arts-(Chell & Althayde, 2009), an innovation foundation based in the UK were reviewed. And finally, there were reviewed the most extensive research projects in this field: INCODE - Innovation Competences Development (Watts et al., 2013, Andreu-Andrés et al., 2017) and FINCODA - Framework for Innovation Competencies Development and Assessment (Marin García et al., 2016), which was developed after a wide literature review of innovation competence models, founding 12 different models with a different degree of specified development and validation.

To analyze how innovation competences are developed, the second part of the literature review was focused on active learning methodologies like problem-based learning, project-based learning and challenge-based education. We deep dived into the roots of project-based learning and problem-based learning (Dewey, 1959, Kilpatrick, 1921, Knoll, 1997, Freeland, 1922), to the more actual authors in these fields like Jonassen & Hung (2008), Krajcik & Blumenfeld (2006), Blumenfeld et al. (2000), Capraro et al. (2013), Savery (2006), Krajcik et al. (1994), Kolmos (2006), Kolmos and De Graff (2007), De Graff and Kolmos (2003), and to specifically project-based learning in engineering education (Perrenet et al, 2000, Cazorla & De los Ríos, 1996, Cazorla et al., 2007; De los Ríos et al., 2010) as well as POPBL (project oriented problem based learning) of Lehman et al. (2008) and the Aalborg case "Problem-Oriented, Project-Organized, Learning" (Kjersdam and Enemark, 1994; Luxhol and Hansen, 1999, Christophersen et al., 1994). Also, the pedagogy of engineering education is discussed (Dym et al., 2005, Li et al., 2015, Saliklis et al., 2009, Kolb, 2006) to later on analyze in depth challenge-based learning (Malmqvist et al., 2015, Johnson et al., 2009, Willis et al., 2017) and multidisciplinary education (Li et al., 2015, Richter and Paretti, 2009, Borrego and Kutler, 2010). Also, different approaches for innovation are analyzed in depth: Design Thinking (Brown, 2008, 2009, Kelley, 2001, Ratcliffe, 2009, Efeoglu et al., 2013) and Product Development (Ulrich- Eppinger, 2008, Fixson, 2009).

Once identified the innovation competences for engineering graduates, and how to develop and measure these competences, we aimed to analyze, 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 analyzed two courses developed at ICT engineering at Technical University of Catalonia (UPC): PDP course (Product Development Project) and the CBI course (Challenge Based Innovation).

PDP is a mandatory project-based course developed since 2012, within the CDIO (Conceive-Design-Implement-Operate) framework (Crawley et al., 2014) that follows the classical product development process described by Ulrich- 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) 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-of-concept functional prototype. They should also define a business model. This course follows the product development process described by Ulrich & Eppinger (2008) and 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 of PDP), a course with a challenge-based learning approach (Malmqvist et al., 2015) combined with Design Thinking methodology (Brown, 2008, 2009, Ratcliffe, 2009).

Challenge Based Innovation (CBI) 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 IdeaSquare at CERN, one of the nodes of the Aalto Design Factory Global Network (DFGN). 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 & 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 (2015).

The methodology for the research is mixed methods (Creswell, 2012, Gallivan, 1997), combining qualitative content analysis of project results and self-reflection documents of the students, and quantitative survey of students' self-perception of innovation competence using the INCODE Barometer self-assessment tool. We compared the results related to innovation competences development in the students participating in PDP (Product Development Project) versus students participating in CBI (Challenge Based Innovation) courses.

The objective of this research is to identify the innovation competences required for future engineering graduates and to define which are the best educational strategies to develop these competences, understanding how to prepare future engineering professionals to innovate and manage the innovation process with a holistic approach

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 and measure those competences, as well as different approaches to innovation. We then define a combination of these existing innovation competences models into a framework used for a qualitative analysis and comparison of the results of the two different experiential learning approaches (PDP and CBI), as well as students' self-perception using the INCODE Barometer, and we discuss conclusions and recommendations for developing educational strategies to develop innovation competences in engineering education.

Objectives and scope

Goal

The goal of this research is to identify the innovation competences required for future engineering graduates and to define educational strategies to better develop these competences. It looks to understanding how to better prepare future engineering professionals to innovate and manage the innovation process with a holistic approach, to be able to influence strategic decisions and going beyond the technical/technological aspects of innovation and becoming ultimately more effective business managers.

The aim is to understand the impact on innovation competences development of two different experiential learning approaches (project-based and challenge-based) and measure their effectivity for better preparing innovative professionals. Being the final objective to understand and recommend how to better design educational strategies to prepare the future engineering graduates with the innovation competences that both industry and society are demanding.

Specific objectives

- To identify the most relevant competences for innovation for engineering students
- To identify the methodology to measure these competences related to innovation for engineering students
- To detect the different pedagogical approaches to develop innovation competences
- To compare results on innovation competences of engineering students going through a "traditional" project-based course PDP (Product Development Projects) vs. engineering students through CBI (Challenge Based Innovation), a multidisciplinary challenge-based combined with Design Thinking project course
- To identify benefits of both CBI and PDP learning experiences related to innovation competences development and detect improvement opportunities for both courses
- To specify a set of recommendations to design educational strategies to better develop innovation competences in future engineering graduates

Scope

The scope of the research is limited to analyzing and comparing project results, reflection documents & self-perception related to innovation competences of UPC Telecom Engineering students that have participated on the CBI (Challenge Based Innovation) course from 2015 to 2018, and UPC Telecom Engineering students that have participated in "traditional" PDP (Product Development Projects) engineering project subjects from 2015 to 2019. Also, the study includes a few Computer Science students that have participated in the CBI course, making no differentiated treatment of the data. As discussed by Marí-Benlloch et al., 2017 one of the key aspects of this, is developing transversal skills, which are the capabilities that can be used for any profession, making no relevant for this work the differences of branches of engineering education.

Expected results and contributions

The expected results of the thesis are:

- To identify the most relevant innovation competences for engineering education
- To identify which pedagogical approaches to innovation are more suitable for developing the different innovation competences in engineering students
- To identify improvement opportunities for project-based and challenge-based courses in engineering education for better developing innovation competences
- To create a set of recommendations for designing better educational strategies for developing innovation competences in engineering students
- To understand the levers to train and prepare engineering students as innovators, defining key learnings that foster innovation competences in engineering curricula

Hypothesis

The introduction of "classic" project courses in ICT engineering following CDIO framework notably improved some of the industry demands for engineering graduates' innovation skills and competences like problem solving, project management, teamwork, communication and real-life industry interaction. Nevertheless, it was identified that there are limitations and some other skills and competences related to innovation can be also aquired.

Within the framework of multidisciplinary projects and challenge-based education, using Design Thinking as an innovation approach, engineering students' competences in innovation like self-efficacy, creativity, multidisciplinary teamwork, business sense, dealing with uncertainty, among other could be improved.

The hypothesis of this research is that innovation competences can be developed through experiential learning approaches like project-based and challenge-based courses, but more comprehensive and extensive innovation competences can be developed through challenge-based learning combined with Design Thinking in multidisciplinary teams, interacting both with students and professors of other disciplines than engineering, like design and business.

Also, multidisciplinary innovation experiential learning can also improve engineering student's self-awareness of the value of their contribution to the innovation process, and self-confidence on their capacity to impact on the whole innovation process. This can better position them at a strategic and management level, going beyond developing or influencing only in technical/technological aspects of innovation.

Chapter 1 – State of the art

The state of the art covers a broad range of topics. Initially, it aims to set the basis of what is innovation and innovation competences, what are the innovation competences required for engineering students and how to measure these competences. Secondly, it focuses on understanding what are the different pedagogical approaches to develop these innovation competences: problem-based, project-based and challenge-based education. Finally, it describes two different approaches to innovation: New Product Development and Design Thinking.

1.1. Innovation

1.1.1. What is innovation?

Innovation must be understood as part of the DNA of any company/institution to create value at every level, both for stakeholders, users, company, and society, and not only as the process of product/service/process development.

Efeoglu et al. (2013) states that "ultimately innovation will not be an R&D topic in an organization anymore but become part for every employee's job, irrespective of his or her position." To embrace innovation, it is key to break down traditional organizational silos and foster the collaboration between different profiles within the company (technological, business and social areas) in an interdisciplinary approach to better operationalize innovation capabilities of a company or institution.

Although innovation is not really a new concept, it is now a "hot topic" probably due to the extremely competitive environment and the speed of changes facilitated or caused by technology and globalization. As far as in 1942, Schumpeter argued that any company looking for making profit must innovate. He considered innovation as an essential driver of competitiveness and the center of economic change, creating the term "creative destruction" in his book Capitalism, Socialism and Democracy (1942). To Schumpeter, innovation is a "process of industrial mutation, that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one". He divided the innovation process into four dimensions: invention, innovation, diffusion and imitation (Śledzik, 2013). Schumpeter emphasized the role of the entrepreneur, who is the one leading innovation, creating ultimately economic impact.

Zahra and Covin (1984) argue that innovation is the "lifeblood of corporate survival and growth", playing a key role in value creation and in maintaining competitive advantages.

There are some interesting quotes from Peters (1987) on innovation: "Wealth in the new regime flows directly from innovation, not optimization; that is, wealth is not gained by perfecting the known, but by imperfectly seizing the unknown". Although this is an interesting approach, it does not replace "business as usual" product development and process improvement, which is fundamental for maintaining and growing existing business. But to have relevant competitive advantages and outperform competition, innovation is needed.

As described by Baragheh et al. (2009), the significance of innovation goes beyond business organizations. The Department of Trade from UK, in 2003 highlighted the link between innovation, jobs, profit and living standards: "If UK-based companies fail to innovate, jobs and profits will suffer, and our standard of living will fall compared with other countries". To both maintain and strengthen their competitive position, organizations and economies must not only innovate, but also promote innovation. Innovation is a key policy and strategic issue (Baragheh et al., 2009).

1.1.2. Defining innovation

A commonly accepted definition can be the one given by OECD (2005): "Innovation is the creation of better or more effective products, processes, services, technologies, or ideas that are accepted by markets, governments, and society. Innovation differs from invention in that innovation refers to the use of a new idea or method, whereas invention refers more directly to the creation of the idea or method itself."

Similarly, and in a more succinct way, Geoffrey Nicholson from 3M said that "R&D is the transformation of money into knowledge. Innovation is the transformation of knowledge into money."

Nevertheless, as pointed by Baregheh et al. (2009), there is a diversity, confusion and overlap between the various definitions for innovation, leading to a situation with a no clear authoritative definition of innovation. On the same line, Adams et al. (2006) highlighted that "the term 'innovation' is notoriously ambiguous and lacks either a single definition or measure". This undermines the understanding of the nature of innovation.

The term has been discussed in literature in many different disciplines, being defined from different perspectives (Damanpour and Schneider, 2006): human resource management, operations management, entrepreneurship, research and development, information technology, engineering and product design, and marketing and strategy. The dominant paradigm of each discipline leads to different definitions of innovation, aligned with those. Most common types of innovation are related to new products, services, materials, new processes and organizational systems (Ettlie and Reza, 1992).

Due to this situation, is particularly interesting the effort of Baragheh et al. (2009) on their article "Towards a multidisciplinary definition of innovation". The authors studied 60 different definitions of innovation from different disciplines, trying to capture the essence and to create an integrative cross-disciplinary definition of the term.

Some of the most common and straightforward definitions of innovation are the ones by Thompson (1965), stating that "Innovation is the generation, acceptance and implementation of new ideas, processes products or services". Similarly, West and Anderson (1996) argue that "Innovation can be defined as the effective application of processes and products new to the organization and designed to benefit it and its stakeholders". With a different approach, Kimberly (1981) defines innovation from the process/stages point of view: "There are three stages of innovation: innovation as a process, innovation as a discrete item including, products, programs or services; and innovation as an attribute of organizations." Finally, we can quote Damanpour (1996) who gives a detailed definition of innovation "Innovation is conceived as a means of changing an organization, either as a response to changes in the external environment or as a pre-emptive action to influence the environment. Hence, innovation is here broadly defined to encompass a range of types, including new product or service, new process technology, new organization structure or administrative systems, or new plans or program pertaining to organization members".

To conclude, the proposed definition from Baregheh et al. (2009) after analyzing 60 definitions state that "Innovation is the multi-stage process whereby organizations transform ideas into new/improved products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace."

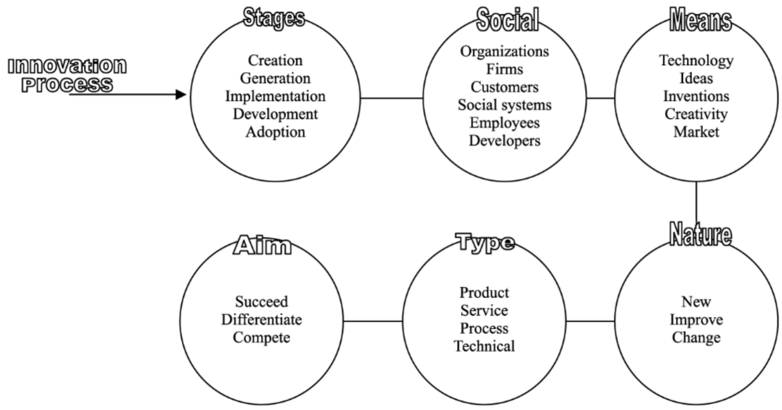


Figure 1. A diagrammatic definition of innovation (Baragheh et al., 2009)

In its diagrammatic multidisciplinary definition (Figure 1), from Baragheh et al. (2009), they cover what they have identified as the six key attributes of innovation definitions:

- Nature of innovation (focused on whether something is new or improved)
- Type of innovation (refers to the type of output or the result of innovation, e.g. product or service)
- Stages of innovation (focused on the steps of an innovation process)
- Social context (refers to social entities and/or environmental aspects affecting it)
- Means of innovation (refers to resources needed i.e., technical, creativity, financial…)
- Aim of innovation (what the organizations want to achieve as an overall result of the innovation process)

1.2. Innovation competences

1.2.1. Why we need innovation competences?

The challenges the world is facing and will face in the future (globalization, climate change, demographic change, among others) need a different response from our education system (Chell & Althayde, 2009). The vast majority of higher education practices were designed for a world that does not exist anymore, the industrial era (Konst et al., 2020). We must equip the students with skills of "global citizenship and cultural sensitiveness, and competences such as critical thinking, initiative, creativity, team working and networking" as Konst et al. (2020) say. It is needed to prepare future generations not only with strong basic skills and technological knowledge, but with the ability and attitude, and wider skills to create new solutions, and to adapt to our rapidly changing world. This rapid adaptation capacity has become even more evident during the last year due to the COVID-19 pandemic, where everybody overnight needed to change their habits.

European Higher Education Area (EHEA)'s main aim in the last few years has become developing students' skills to allow them a greater success in the labor market, through incorporating better academic education processes (Marí-Benlloch et al., 2017). As these authors mention, one of the key aspects of this, is developing transversal skills, which are the capabilities that can be used for any profession. This means that innovation competences are no different from one profession to another. The differences are in the "technical" skills, as innovation skills are needed and can be applied in any field, as ultimately, they are a way to tackle complex challenges or problems.

From the industry or business perspective, innovation capabilities are the most determinant aspect of a company performance (Martínez-Gómez et al., 2016, Mone et al., 1998). Thus, both at an organizational level as well at a personal level, innovation is important, and developing innovation competences is a must for companies' competitiveness.

The education system needs to prepare future generations with "the skills for innovation to a greater degree than ever before: the confidence and insight to generate a novel idea or new approach; the motivation, commitment and resilience to pursue that idea; the leadership, energy and dynamism to communicate their vision to others and drive it forward from concept to reality". And for these skills to be taught, it is mandatory that we are able to identify and measure them (Chell & Althayde, 2009).

1.2.2. Defining Innovation competences

Innovation competences are often associated with those for entrepreneurship and even though they are related, it is good to differentiate them.

Entrepreneurship is normally associated with starting a business whereas innovation is also about wider "economic and social wellbeing" (Chell & Althayde, 2009). Simply put, innovators are people who generate new ideas and entrepreneurs are those who take ideas, whether are new or not, to market.

As defined by Kairisto-Mertanen et al. (2012), innovation competences are "the learning outcomes which refer to knowledge, skills and attitudes needed for the innovation activities to be successful".

According to existing research, some of the most relevant innovation competences, as described in different papers (Karisto-Mertanen et al., 2012, Marín-García et al., 2011, Marín-García et al., 2013) are: creativity, creative problem solving, problem identification, independent thinking, openness to new ideas, research focused, teamwork, forward-looking approach, among others.

However, there is still much debate on what exactly are the innovation capabilities needed, and specially what are the instruments to be used for identifying and measuring the acquisition of these innovation skills (Marí-Benlloch et al., 2017). Various organizations and scholars have put forward their view of innovation competences, that are analyzed in this study.

To identify the innovation competences required for engineering graduates, the literature review was focused on competences demanded by relevant engineering institutions (ABET, CDIO and ENAEE – EUR-ACE®), with emphasis on innovation competences. On a more specific level, it was also reviewed the competences defined by the Spanish Ministry of Education and the UPC. Also, the most exhaustive studies in Europe on innovation competences were reviewed: INCODE, FINCODA and NESTA. This was also complemented with other more specific articles about ICT engineers' generic skills and academia-industry cooperation literature defining innovation competences needed for engineers. In summary, these are the sources reviewed for identifying the innovation competences:

1) Relevance of the institutions defining generic competences for engineering education: ABET (ABET, 2017, Shuman et al., 2005), ENAEE / EUR-ACE® (2020), CDIO (Crawley et al., 2011, 2014), Spanish Ministry of Education (2009) and UPC (Córdoba et al., 2007).

2) Relevance and breadth of innovation competences studies: INCODE (Watts et al., 2013, 2014), FINCODA (Marin-García et al., 2016) and NESTA (Chell & Althayde, 2009)

3) Studies on generic skills for ICT (Information & Communication Technology) engineers (Llorens et al., 2009, 2010)

4) DEMOLA academia-industry cooperation program defining innovation competences (Pippola et al., 2012)

It was observed that neither ABET, ENAEE / EUR-ACE® nor CDIO do not explicitly mention innovation competences. Nevertheless, in all cases in their listed competences or skills lists, there are innovation competences although they are not "branded" as that (i.e., critical thinking, teamwork, leadership, among others). The same happens with the Spanish Ministry of Science and Education when defining the competences for telecommunications Engineers (2009) or the ICE (Education Sciences Institute) from UPC, when defining generic competences for engineering students. In these cases, 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 or DEMOLA.

The most exhaustive studies on innovation skills and abilities are those realized by two extensive research projects: INCODE and FINCODA. INCODE, the Innovation Competencies Development project, focuses on higher education, while FINCODA is meant to be applied in companies or other organizations. FINCODA considers innovation competences as a collection of capacities, skills, and behaviors and was created as a new innovation competence model that complements and extends the existing ones (previously analyzing more than 12 innovation competence models, Marin-García et al., 2016). Also, NESTA (National Endowment for Science, Technology and the Arts of United Kingdom) developed a set of innovation competences and a tool to measure them after a broad literature review and extensive testing in United Kingdom.

Finally, it is interesting the listed competences by Pippola et al. (2012) focusing on engineers' competences needed by business and industry, probably not with the academic or scientific depth as the other studies but with a very pragmatic vision from the industry.

Below is a summary of each of the identified sources regarding innovation competences.

1.2.2.1. INCODE - Innovation Competencies Development

The Innovation Competencies Development (INCODE) project is a European project developed by four Universities: Turku University of Applied Sciences from Finland, Hamburg University of Applied Sciences from Germany, Karel de Grote University College Antwerp from Belgium and the Universitat Politècnica de Valencia from Spain.

The INCODE innovation construct is based on three dimensions at a competence level: individual, interpersonal and networking as shown in Figure 2, following the model proposed by Penttilä and Kairisto-Mertanen (2012) for measuring innovation competences in higher education students.

As defined by Watts et al. (2013), "the individual capacity integrates the behaviors or skills that allow a person to innovate in the personal execution of tasks. The interpersonal capacity enhances the individual ability to innovate through the interaction with a group and represents the behaviors or skills that make others move towards the objective. The networking capacity represents the behaviors or skills that enable a group to find appropriate solutions in the process of completing tasks in a broader environment than usual."

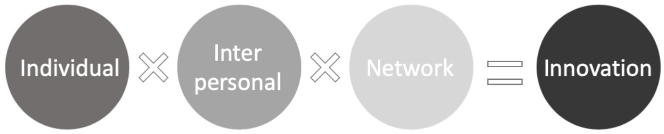


Figure 2. Innovation competence model. Adapted from Penttilä and Kairisto-Mertanen (2012)

These three dimensions are better described and defined by Marin-Garcia et al. (2015), structuring the three dimensions in specific innovation competences defined as Individual: creativity and critical thinking, Interpersonal: teamwork and leadership, Network: networking and impact as shown in Figure 3.

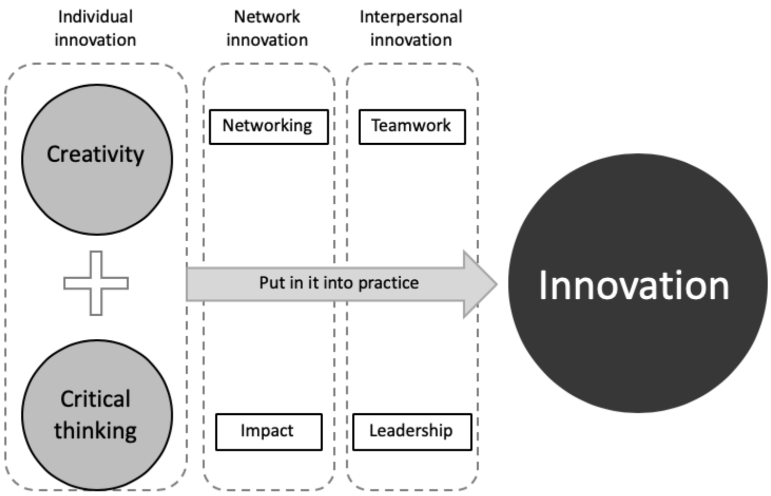


Figure 3. Innovation model. Adapted from Marin-Garcia et al. (2015)

The Innovation Competencies Development (INCODE) Barometer aims to contribute in the developing and assessing innovation competences in higher education contexts (Watts et al., 2013). It is a scoring rubric that covers the three dimensions of skills and capacities defined by Penttila and Kairisto-Mertanen (2012): individual, interpersonal and network. The Barometer can be used in several ways: self-assessment, peer assessment and also by teachers to assess students' learnings outcomes.

Within the Barometer there are two groups of rubrics to assess innovation competence performance: Rubrics 1, 2 & 3 to for teacher/peer assessment and rubrics 4, 5 & 6 for self-assessment. They differ in the choice of scale: 1-10, 1-5 and 1-3 and a category for Not observed or Not demonstrated.

Watts et al. (2014) argue that "no formal system has been regulated to acquire and assess the skills and capacities involved" regarding the certification of the components of innovation competence. Thus, INCODE is a good step forward on systematizing the assessment of innovation competences, aligned with the methods proposed by Prus & Johnson (1994) to assess "professional skills" in students, with Atman et al. (2000) that mentioned metrics on the process of innovation and individual's creative personality and Bandura's (1997) proposed reflective essays and self-efficacy concept.

1.2.2.2. FINCODA - Framework for Innovation Competencies Development and Assessment

According to FINCODA (Framework for Innovation Competencies Development and Assessment) website (2017), "The FINCODA project was born out of a recognition of how important innovation is to both the business and academic worlds". They sate that "without innovation, an organization's growth can be severely stunted". They also mention that for academic institutions, it is crucial to prepare future professionals with the key skills for innovation to succeed in the workplace. Their capacity to train students in innovation is fundamental, as they are the future of professions and future leaders. Due to the aforementioned, FINCODA project was born, with the aim of developing a "reliable and valid tool for measuring and developing individual's capacity for innovation".

The FINCODA Innovation Barometer Assessment Tool is a psychometric tool that measures individuals' capacity for innovation, breaking it in 5 areas and assessing capacity of the individual in each of them separately. The research behind the tool has been developed by FINCODA partners, a mix of academic and industry players bringing expertise from across Europe, with the coordination and administration of the project led by Turku University of Applied Sciences, Finland.

The composition of the consortium was:

University partners:

- Turku University of Applied Sciences (TUAS) (Finland)
- Universitat Politècnica de València (UPV) (Spain)
- University of Applied Sciences Utrecht (Netherlands)
- Manchester Metropolitan University (UK)
- Hamburg University of Applied Sciences (Germany)

Business partners:

- Elomatic Ltd (Finland)
- Lactoprot (Germany)
- John Caunt Scientific Ltd (UK)
- Carter & Corson Business Psychologists (UK)
- Schneider Electric España SA (Spain)
- Celestica (Spain)
- Meyer Turku Oy (Finland)
- ECDL (The Netherlands)

Additional partner:

- Chamber Link (trading as Business Support Solutions) (UK)

The FINCODA tool (Marin-García et al., 2016) was developed after a wide literature review of innovation competence models, founding 12 different models with a different degree of specified development and validation summarized in Table 1.

	Marin-Garcia, Ramirez Bayarri, & Andreu Andres (2015)	i-skills	Kleysen & Streer (2001)	Scott & Bruce (1994)	Waychal, Mohanty & Verma (2011)	Kirton (1976)	Berdows & Evers (2011)	Cerinsek & Dolinsek (2009)
Creativity	Creativity	Creativity	Generativity	Generate creative ideas	ability to generate ideas	Innovator	Creativity/innovation/change	Creativity
Critical Thinking	Critical thinking	Critical thinking Risk asessment	Opportunity exploration AND Formative investigation	Searches out new technologies, processes…	Industry vision stretch mindset		Ability to conceptualize Problem Solving/analytic Risk taking	Ability to Observe Curiosity
Influential Initiative	Leadership	Confidence/ resilience Initiative/ entrepreneurship Project management	Championing AND Application	Promotes and champions ideas to others Investigate and secures founds Develops adequate plans	ownership to the organization		Coordinating Decision making Leadership/influence Managing conflict Planning and organizing visioning	Autonomy Motivation Ambitiousness Intrapreneurship
External collaboration	Network	Networking			external networking relationships			
Internal collaboration	Teamwork	Negotiation Communication Leadership & teamwork Global Mindset			internal networking relationships		Communicating	
Value Added	Impact	Valorization			focus on tasks /decision-making competencies	Adaptor		Intrapreneurship
Use of problem-solving tools		Problem Solving		Problem solving-style			Problem Solving/analytic	

Table 1. Comparative of innovation competence models (Marin-García et al., 2016)

As INCODE was focused on the higher education field, FINCODA is aimed to be applied in at the companies/industry/organizations level, observing and measuring innovative behavior in the workplace. FINCODA was created as a new innovation competence model that complements and extends the existing ones, considering innovation competence as the group of capacities, skills or behaviors that allow an individual to innovate (Marin-García et al., 2016).

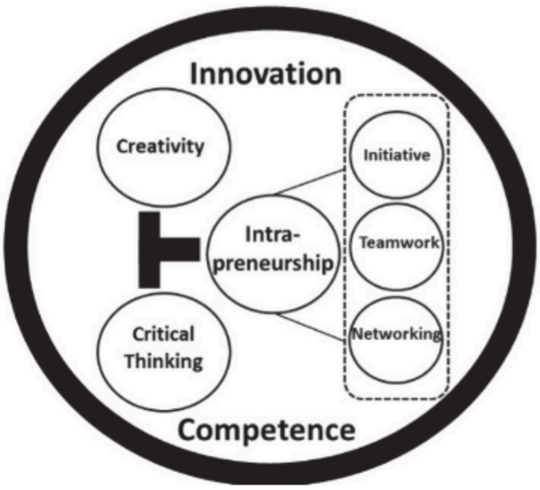


Figure 4. FINCODA Innovation Competence Model (Marin-García et al., 2016)

As shown in Figure 4, there are three dimensions that comprise the FINCODA innovation competence model: creativity, critical thinking and intrapreneurship. This last, being composed by initiative, teamwork and networking. The detailed explanation of each competence is explained in Table 2.

Creativity	Critical thinking	Intrapreneurship		
		Initiative	Teamwork	Networking
ability to transcend (think beyond) traditional ideas, rules, patterns or relationships, and to generate or adapt meaningful alternatives, ideas, products, methods or services independently of their possible practicality and future added value	ability to analyze and deconstruct issues with a purpose (evaluate advantages and disadvantages, foresee how events will develop, estimate the risks involved)	ability to take decisions or carry out actions to operationalize ideas that foster positive changes, as well as to mobilize and manage creative people and those who have to implement ideas	ability to work efficiently with others in a group	ability to involve external/outside stakeholders (outside the work group)

Table 2. FINCODA Innovation Competences Elements Definition (Marin-García et al., 2016)

As described by Marin-García et al. (2016), the objective of the tool was to develop this model into a competence diagnosis tool to aid companies in the identification of the most suitable people to include in teams that encourage innovation and to offer value in the selection, management and development of innovator talent, both in universities and companies.

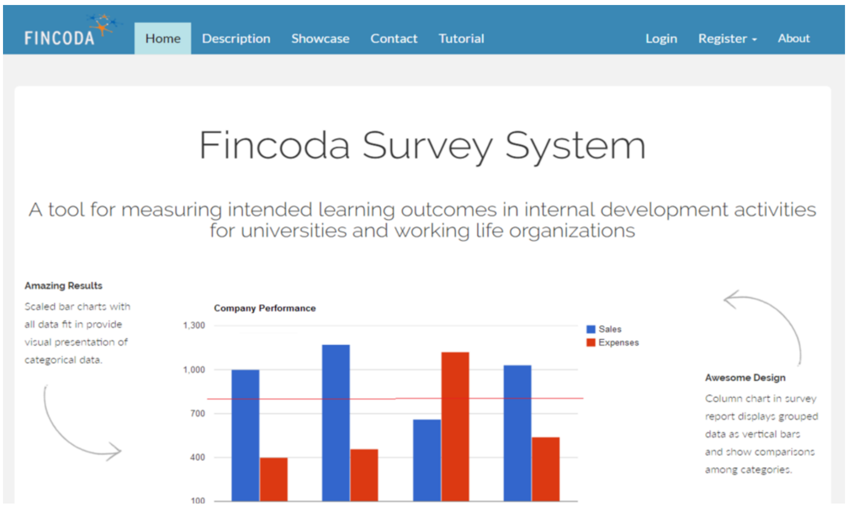


Figure 5. FINCODA Survey system report feedback example (www.fincoda.eu/how-it-works, accessed on 15th March 2021)

As explained in their website, the FINCODA online survey system allows individuals, businesses and universities to measure a person's innovative capacity. Also, it provides both individual and group reports that support and assist users to grow as "innovators". Once people complete the FINCODA survey, they have access to a report that identifies areas for development of their innovation competences, in relation to each of the five dimensions: Creativity, Critical Thinking, Initiative, Team Working & Networking. The development feedback is specific to each of the five innovation dimensions. An example of part of the development report feedback is shown in Figure 5.

1.2.2.3. NESTA - National Endowment for Science, Technology and the Arts of United Kingdom

NESTA, the National Endowment for Science, Technology and the Arts of United Kingdom, which aims to transform the UK's capacity for innovation had developed a research study (Chell & Althayde, 2009) to identify which are the competences needed for innovation and created a tool to measure them.

As explained by the authors, the skills were identified through a literature review and through testing the concepts with separate focus groups of young people and teachers from different disciplines in schools and colleges in Greater London and Hampshire.

They have defined five generic skills that underpin innovative behavior and form a set of attributes clearly linked to the innovation process:

- Creativity (imagination, connecting ideas, tackling and solving problems, curiosity)
- Self-efficacy (self-belief, self-assurance, self-awareness, feelings of empowerment, social confidence)
- Energy (drive, enthusiasm, motivation, hard work, persistence and commitment)
- Risk-propensity (a combination of risk tolerance and the ability to take calculated risks)
- Leadership (vision and the ability to mobilize commitment).

1.2.2.4. ABET - Accreditation Board of Engineering and Technology

Originally founded in 1932 as the Engineers' Council for Professional Development (ECPD), it developed into the Accreditation Board for Engineering and Technology in 1980 with an emphasis on accreditation. In 2000 it adopted the Engineering Criteria 2000 (EC2000), focusing on learning outcomes (what students learn) rather than what is taught.

As described by Shuman et al. (2005), ABET, when developing its new accreditation criteria in 2005 reaffirmed a list of "hard" engineering skills and also introduced another set of "professional" skills.

These "professional" skills can be divided in two categories (Shuman et al., 2005):

- Process skills: communication, teamwork, and the ability to recognize and resolve ethical dilemmas
- Awareness skills: social and global factors impact understanding, contemporary issues knowledge, and ability for lifelong learning.

These professional set of skills, although they are not "branded" as innovation skills, can clearly relate to innovation competences defined by INCODE, FINCODA or NESTA.

1.2.2.5. ENAEE - European Network for Accreditation of Engineering Education / EUR-ACE®

Similar to ABET, the European Network for Accreditation of Engineering Education with its EUR-ACE® label, they promote engineering education quality "across Europe and beyond".

ENAEE (2020) is aimed at enhancing "the quality of the education of engineering graduates and support their ability to fulfil the needs of economies and of society".

As follows in Table 3, a synthesis of the generic competences defined by ENAEE / EUR-ACE® (2020).

Knowledge and Understanding • "...mathematics and other basic sciences underlying their engineering specialization..." • "...awareness of the wider multidisciplinary context of engineering..."	**Engineering Practice** • "...solving complex problems" • "awareness of non-technical -societal, health and safety, environmental, economic and industrial – implications of engineering practice" • "awareness of economic, organizational and managerial issues (such as project management, risk and change management) in the industrial and business context"
Engineering Analysis • "ability to analyze complex engineering products, processes and systems...and correctly interpret outcomes" • "ability to identify, formulate and solve engineering problems... and to recognize the importance of non-technical –societal, health and safety, environmental, economic and industrial – constraints"	**Making Judgements** • "... gather and interpret relevant data and handle complexity...to inform judgements that include reflection on relevant social and ethical issues" • "... manage complex technical or professional activities or projects in their field of study, taking responsibility for decision making"
Engineering Design • "ability to develop and design complex products, processes and systems..." considering "non-technical – societal, health and safety, environmental, economic and industrial– implications	**Communication and Team-working** • "ability to communicate effectively information, ideas, problems and solutions..." • "ability to function effectively in a national and international context, as an individual and as a member of a team and to cooperate effectively with engineers and non-engineers."
Investigations • "ability to conduct searches of literature... in order to pursue detailed investigations and research of technical issues"	**Lifelong Learning** • "ability to follow developments in science and technology."

• "… ability to design and conduct experimental investigations, interpret data and draw conclusions"	

Table 3. Programme Outcomes for Bachelor Degree Programmes (ENAEE / EUR-ACE®, 2020)

From the list of competences defined by ENAEE / EUR-ACE®, the ones that directly refer to innovation competences, or the ones that on a second level mention innovation competences are: Knowledge and Understanding, Investigations, Engineering Practice, Making Judgements and Communication and Team-working.

1.2.2.6. CDIO - Conceive Design Implement Operate - initiative

Aimed to reducing the gap between industry demands and engineering education, the CDIO (Conceive-Design-Implement-Operate) was born as a joint project of MIT (Massachusetts Institute of Technology) and three Swedish universities: Chalmers, KTH and Linköping, with the specific aim of reducing the gap in the skills of engineering graduates, getting to the first Syllabus in 2001 and formed the Initiative in 2004.

In the CDIO Syllabus v2.0, Statement of Goals for Engineering Education (Crawley et al., 2011), level two there are not specific mentions to or direct "branding" of competences as innovation. Nevertheless, as in ABET we can directly relate many of them to innovation.

1. Disciplinary knowledge and reasoning 1.1 Knowledge of underlying mathematics and science 1.2 Core fundamental knowledge of engineering 1.3 Advanced engineering fundamental knowledge, methods and tools	**2. Personal and professional skills and attributes** 2.1 Analytical reasoning and problem solving 2.2 Experimentation, investigation and knowledge discovery 2.3 System thinking 2.4 Attitudes, though and learning 2.5 Ethics, equity and other responsibilities
3. Interpersonal skills: teamwork and communication 3.1 Teamwork 3.2 Communications 3.3 Communications in foreign languages	**4. Conceiving, designing, implementing, and operating systems in the enterprise, societal and environmental context** 4.1 External, societal and environmental context 4.2 Enterprise and business context 4.3 Conceiving, systems engineering and management 4.4 Designing 4.5 Implementing 4.6 Operating 4.7 Leading engineering endeavors 4.8 Entrepreneurship

Table 4. CDIO Syllabus v2.0, CDIO Syllabus v2.0 at the Second Level of Detail (Crawley et al., 2011)

From the CDIO level 2 summarized in Table 4, the competences that can be directly linked to innovation, based on the other studies mentioned in innovation competences like INCODE, FINCODA and NESTA are:

2.1 Analytical reasoning and problem solving, 2.2 Experimentation, investigation and knowledge discovery, 2.3 System thinking, 3.1 Teamwork, 3.2 Communication, 4.1 External, societal and environmental context, 4.2 Enterprise and business context, 4.7 Leading engineering endeavors and 4.8 Entrepreneurship.

1.2.2.7. Spanish Ministry of Science and Innovation

In the competences summarized in Table 5, defined by the Spanish Ministry of Science and Innovation in 2009 for the Telecommunications Engineers there is not any specific mention to innovation. Nevertheless, there are several competences that are directly related to innovation like versatility to adapt to new situations, problem solving, creativity, communication, leadership, business management and multidisciplinary teamwork.

A. Capacidad para redactar y desarrollar proyectos en el ámbito de su especialidad.
B. Conocimiento de materias básicas y tecnologías, que le capacite para el aprendizaje de nuevos métodos y tecnologías, así como que le dote de una gran versatilidad para adaptarse a nuevas situaciones.
C. Capacidad de resolver problemas con iniciativa, toma de decisiones, creatividad, y de comunicar y transmitir conocimientos, habilidades y destrezas, comprendiendo la responsabilidad ética y profesional de la actividad del ingeniero técnico de telecomunicación.
D. Capacidad para la dirección de las actividades objeto de los proyectos del ámbito de su especialidad.
E. Conocimientos para la realización de mediciones, cálculos, valoraciones, tasaciones, peritaciones, estudios, informes, planificación de tareas y otros trabajos análogos en el ámbito de su especialidad.
F. Facilidad para el manejo de especificaciones, reglamentos y normas de obligado cumplimiento.
G. Capacidad de analizar y valorar el impacto social y medioambiental de las soluciones técnicas.
H. Conocer y aplicar elementos básicos de economía y de gestión de recursos humanos, organización y planificación de proyectos, así como de legislación, regulación y normalización en las telecomunicaciones.
I. Capacidad de comunicar, tanto por escrito como de forma oral, conocimientos, procedimientos, resultados e ideas relacionadas con las telecomunicaciones y la electrónica.
J. Capacidad de trabajar en un grupo multidisciplinar y en un entorno multilingüe y de comunicar, tanto por escrito como de

forma oral, conocimientos, procedimientos, resultados e ideas relacionadas con las telecomunicaciones y la electrónica.

Table 5. Generic competences for ICT students (Spanish Ministry of Science and Innovation, 2009)

1.2.2.8. UPC (Technical University of Catalonia)

In the list of generic competences defined by Education Sciences Institute (ICE) from UPC (Córdoba et al., 2007) listed in Table 6, we find on the first place Entrepreneurship and Innovation. Also, communication and teamwork are mentioned, but as a separate skill and not related to innovation which in fact they are.

It is worth to notice that Innovation is specified as an independent competence as well as teamwork of communication. While research in innovation competences define the last two as skills of innovation competences.

1. Entrepreneurship & Innovation
2. Sustainability and social commitment
3. 3rd language (English)
4. Efficient oral and written communication
5. Teamwork
6. Solvent use of information resources
7. Autonomous Learning

Table 6. Generic competences UPC (Córdoba et al. 2007)

1.2.2.9. Studies on generic skills for ICT engineers (Information & Communication Technology)

Specifically, for ICT professionals Llorens et al. (2009, 2010) after a broad literature review summarize a list of skills for these engineering professionals listed in Table 7 and Table 8, focusing on inter-personal skills and abilities than on knowledge and technical expertise. As observed in their two articles, they define two different, yet very similar lists of skills for ICT professionals.

• Assertiveness • Communication skills • Negotiation skills • Planning skills • Information research skills • Teamwork • Company loyalty • Commitment to learning • Self-control • Creativity	• Empathy • Flexibility • Taking the initiative; being proactive • Innovation • Leadership • Empowerment • Objective or task oriented • Customer oriented • Analytical thought • Problem solving

Table 7. The 20 Generic Skills for ICT Professionals (Llorens et al., 2010)

• Change management • Commitment to customer service • Commitment to excellence • Communication • Creativity • Decisiveness • Empathy • Innovation • Motivation	• Leadership • Knowledge management • Negotiation • Objective oriented • Personal development • Persuasiveness • Proactive • Problem-solving skills • Strategy and planning • Teamwork

Table 8. Professional and Interpersonal Skills for ICT Specialists (Llorens et al., 2019)

Although both lists are similar, they have slight differences. In summary, we can say that the innovation competences we can consider from them are: Communication skills, Strategy and Planning skills, Information research skills, Teamwork, Creativity, Empathy, Flexibility, Taking the initiative, being proactive, Innovation, Leadership, Empowerment, Customer oriented, Analytical thought, Problem solving, Motivation, Change management and Knowledge management.

Interestingly in both lists, we can find innovation as a competence like in UPC list of generic competences. Also, as independent competences we found in both lists many skills which are building blocks of innovation competences like creativity, teamwork, problem-solving and communication. It is interesting to highlight also that empathy and customer-oriented skills are mentioned, as these are fundamental aspect of user-centered innovation (empathy for the user).

It is also worth to mention that these generic competences or professional skills might not differ for any other professionals than ICT engineers and could apply to any other engineering professional. Also, it is important to highlight the role of ICT in the last years as an enabler or driver of innovation, with most innovation projects having an ICT component.

1.2.2.10. DEMOLA academia-industry cooperation program defining innovation competences

As described by Pippola et al. (2012), an interesting initiative is Demola (2020), a model started in 2008 in Finland to create an environment for co-creation and innovation education to co-create new solutions to real-life problems between university and industry. Demola is an open innovation platform for students and companies to develop innovation projects.

Demola aims to tackle the competences business and industry will need. As Pippola et al. (2012) mention, we are moving from an information society into an experience and experimental society, and companies' business logic will be more based on innovations.

The key competences in this new environment, as discussed by Pippola et al. (2012) are: willingness and ability to work in a new way, ability to network, internationalism, business skills, technological skills, environmental skills, service skills and design skills.

The authors state also that "super individuals" will not be needed in the future, as necessary competences will (and must be) found in teams and networks.

Specifically, for engineering professionals, it is mentioned that having engineer's core skills is of course a critical factor, but this is not enough. The competences needed for engineers that will be important in the future, beyond core technical skills are: Creativity and innovativeness, Business skills, Usability of technology and productization, Risk management, engineer's ability to see things three steps ahead, sense of responsibility and ethics, shared expertise, collective learning and facilitating skills, problem-based thinking, reflection of own activity, collaboration, ability to communicate own expertise to others, understanding of differences in people as potential, ability to stand stress and uncertainty, ability to learn by doing (Pippola et al., 2012).

Even though this list might not have the academic or scientific rigor of the other studies aforementioned, it reflects an interesting pragmatic perspective from the industry and business.

Finally, in Table 9 a summary of the identified innovation competences considered the most relevant ones for this research is presented. 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.

This list is based on specific innovation competences mentioned in literature and generic competences for engineering professionals defined in literature. Among the second, we selected the ones that are related to innovation.

SOURCE	PROPOSED SET OF INNOVATION COMPETENCES	
INCODE The Innovation Competencies Development project (Watts et al., 2013, 2014)	• Individual: creativity and critical thinking • Network: networking and impact	• Interpersonal: teamwork and leadership
FINCODA Framework for Innovation Competencies Development and Assessment (Marin-García et al., 2016)	• Creativity • Critical thinking	• Intrapreneurship: initiative, teamwork and networking
NESTA National Endowment for Science, Technology and the Arts of United Kingdom (Chell & Althayde, 2009)	• Creativity (imagination, connecting ideas, tackling and solving problems, curiosity) • Self-efficacy (self-belief, self-assurance, self-awareness, feelings of empowerment, social confidence)	• Energy (drive, enthusiasm, motivation, hard work, persistence and commitment) • Risk-propensity (a combination of risk tolerance and the ability to take calculated risks) • Leadership (vision and the ability to mobilize commitment)
ABET	**Process skills:**	**Awareness skills:**

Accreditation Board for Engineering and Technology (ABET, 2018, Shuman et al., 2005)	• Communication • Teamwork • ability to identify and solve ethical dilemmas	• Social and global factors impact understanding • Contemporary issues knowledge • Ability for lifelong learning
ENAEE – EUR-ACE® European Network for Accreditation of Engineering Education (2020)	• Knowledge and Understanding • Investigations	• Engineering Practice • Making Judgements • Communication and Team-working
CDIO Syllabus v2.0 Statement of Goals for Engineering Education (Crawley et al., 2011)	**Competences related with innovation:** • Analytical reasoning and problem solving • Experimentation • Investigation and knowledge discovery • System thinking • Teamwork	• Communication • External societal and environmental context • Enterprise and business context • Leading engineering endeavors • Engineering entrepreneurship
Spanish Ministry of Science and Innovation Competences defined for Telecommunications Engineers (2009)	• Versatility to adapt to new situations • Problem solving • Creativity • Communication	• Leadership • Business management • Multidisciplinary teamwork
UPC – Technical University of Catalonia Generic competences defined by Science Education Institute (ICE) from UPC (Córdoba et al., 2007)	• Entrepreneurship & Innovation • Sustainability and social commitment • Efficient oral and written communication	• Teamwork • Solvent use of information resources
Professional and Interpersonal Skills for ICT Specialists Llorens et al. (2009, 2010)	• Communication skills • Strategy and Planning skills • Information research skills • Teamwork • Creativity • Empathy • Flexibility • Taking the initiative; being proactive	• Innovation • Leadership • Empowerment • Customer oriented • Analytical thought • Problem solving • Motivation • Change management • Knowledge management
DEMOLA academia-industry cooperation program defining innovation competences (Pippola et al., 2012)	• Creativity and innovativeness • Business skills	• problem-based thinking • reflection of own activity • collaboration • ability to communicate own expertise to others

	• Usability of technology and productization • Risk management • engineer's ability to see things three steps ahead • sense of responsibility and ethics • shared expertise • collective learning and facilitating skills	• understanding of differences in people as potential • ability to stand stress and uncertainty • ability to learn by doing.

Table 9 - Innovation competences identified for engineering education according to different standards

1.2.3. A note on multidisciplinarity and leadership

As discussed above, multidisciplinarity is a fundamental aspect of innovation and when working in teams, especially in multidisciplinary ones, leadership emerges as a key competence for managing innovation processes and projects, where dealing with uncertainty plays a decisive role. Thus, as follows we discuss multidisciplinarity and leadership as both are in the backbone of innovation competences needed for future professionals.

From working in teams to working in multidisciplinary teams

Constructivist learning theories acknowledge learning as a social activity (Minneman, 1991), also Rittel and Webber (1973) highlighted that initial stages of the design process are "inherently argumentative", having the designer continuously raising questions and discussing with others pros and cons of the different responses. In the same line, Bucciarelli (1994) described "design as a social process", where teams create and discuss (and negotiate) decisions. He also described that each team member has an own set of values and representations that work as a filter during team interactions. Thus, the result of the design process is not a simple summation of participants' contribution, but an intersection of their products/values.

Collaboration is based on sharing and co-developing knowledge, getting support from other team members. According to Parlett and King (1970), the probability of increasing motivation is among the most important influential factors of teamwork and the results of teamwork can be higher than the sum of individual performances (Peacock, 1989).

Having diverse skillsets within a team create complementarity among team members. This avoids one of the weaknesses of homogenous teams, where the lack of differences gets them to tend to agree on perspectives of peers. This is due to their mindset similarities, described by Perry and Euler (1988). Diverse and heterogeneous teams potentially question, critique and discuss everything, thus increasing the chance of emergence of innovative ideas (Hackman, 1983).

Bradshaw (1989) concluded that heterogeneous teams perform better, when comparing highly intellectual heterogeneous and homogenous teams. And also, there are positive effects on growing self-confidence on the individuals as well as increased tolerance (Buchanan, 1989).

In United States, the National Innovation Initiative (2005) report defined that "innovation arises from the intersections of different fields or spheres of activity". In order to do so, multidisciplinary education can take a fundamental role in shaping these future innovators thinkers.

Multidisciplinary or interdisciplinary?

As discussed by Li et al. (2015), several authors use the words "multidisciplinary" and "interdisciplinary" interchangeably and as synonyms, which can draw to confusion. Thus, it is good to clarify these definitions and highlight some differences.

According to the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine (2005) on their report "Facilitating interdisciplinary research", the definition of interdisciplinary is "integrating information, data, techniques, tools, perspectives, concepts and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems beyond the scope of a single discipline." This suggests that interdisciplinary education merges existing expertise to synthetize new knowledge (Richter and Paretti, 2009).

On the other hand, multidisciplinary is defined on the aforementioned report as "research that involves more than a single discipline in which each discipline makes a separate contribution". This could be seen as a "temporary or weak combination of contributions from multiple disciplines" (Borrego and Cutler, 2010), where team members remain attached to the processes, methods and concepts of their belonging fields (Stokols et al., 2008). On the contrary, interdisciplinary team members collaborate intensively to integrate their diverse perspectives, even "while remaining anchored to their respective fields".

At the end, all above mentioned about multidisciplinarity is oriented to create value, either knowledge, products, services, processes… Innovation is about creating value, and although is becoming a buzzword, companies and employers are more and more looking for profiles capable of creating value. Future professionals need to be able to work in multidisciplinary teams and to understand the innovation and value creation process.

Leadership

When talking about teamwork, the term leadership easily emerges as a relevant topic. Also, there is a trend in industry and institutions reporting the need for undergraduate institutions to develop leadership abilities in their engineering graduates (Northouse, 2013).

There are four common aspects in leadership research, as synthetized by Northouse (2013): leadership is a process, it involves influence, occurs in groups and involves common goals. This author is who defines leadership as "a process whereby an individual influences a group of individuals to achieve a common goal".

Interestingly, Grint (2007) describes that leadership skills and knowledge can be taught, but to be effective it needs wisdom, which can only be obtained through experience.

According to Knight and Novoselich (2017), there are disagreements among faculty members and administrators on the most effectives way to develop leadership skills among engineering students. Also, in many cases this is coming from students' co-curricular activities and is being related to student's self-reported leadership skills. These should not be the main paths to fostering these types of skills, as it can't be guaranteed that all students will engage in these types of activities.

Thus, working in teams and specifically in multidisciplinary teams could bring this wisdom and experience real life work relationships that promote and develop necessary leadership skill in engineering students.

Farr and Brazil (2009) highlight leadership as a key element in the engineering profession to remain relevant in an era of outsourcing and global competition. Engineering students must develop the capability of leading multidisciplinary teams, combining "technical ingenuity with business acumen", going beyond design and scientific inquiry into professional leadership and entrepreneurship.

Meckl et al. (2009) highlight adaptability to change, synthetizing multiple perspectives, change management and merging engineering, business and social perspectives as important competencies for engineers' undergraduate to meet "changing needs of the twenty-first century".

Similarly, as summarized by Ahn et al. (2014), the importance of leadership in undergraduate engineers has been underlined in several reports and initiatives like ABET (2017) and NAE (2004). According to NAE "engineers must understand the principles of leadership and be able to practice them in growing proportions as their careers advance". Also, ABET's (2017) accreditation criteria for engineering programs in USA include not only technical and analytical skills, but leadership related abilities like effective communication, functioning in multidisciplinary teams, and understanding the impact of engineering solutions in a societal context.

To put these leadership abilities into practice, working in multidisciplinary teams of students in real life projects, engaging with real stakeholders and managing societal needs as requirements can be an effective way to achieve this well needed capacity.

1.3. Measuring Innovation competences

As important as defining what are the innovation competences for an innovation pedagogy, it is how to assess the accomplishment of the learning objectives, in order to validate de effectiveness of the methodology (Watts et al., 2013).

Six different types of methods have been proposed by Prus & Johnson (1994) to assess "professional skills" in students, that can directly apply to assess innovation competences. These methods include:

- Tests & examinations
- Measures of attitudes and perceptions (self and third-party reports)
- Portfolios
- Competency measures (performance appraisals and stimulation)
- Behavioral observation
- External examiner

The authors highlight portfolios (projects' results), and performance appraisals can provide a good assessment of student outcomes, providing a direct measure of what has been learned in a course.

More specifically for innovation competences, Atman et al. (2000) mention metrics focused on the process of innovation and individual's creative personality. They propose surveys, questionnaires, concept maps, observations, grades as methods for evaluating design capabilities.

Also, Bandura (1997) found that reflective essays written by students can be a good predictor of design performance, as self-efficacy (belief in one's own abilities toward a given task) play a fundamental role in effectively executing innovation.

There are not so many measurement tools for innovative competences. One of them is KIA (Kirton's innovation-adaptation) measure, developed for people working in large corporations and designed to identify those with entrepreneurial attitudes and those other who adapted their behavior to follow organizational requirements. It is designed to measure the propensity to innovate vs. the propensity to adapt (Bobic et al., 1999).

Watts et al. (2014) argue that "no formal system has been regulated to acquire and assess the skills and capacities involved" regarding the certification of the components of innovation competence.

It is in this context where the INCODE Barometer described above, can be highlighted as one of the most comprehensive and systematic efforts in developing a tool to measure innovation competences in higher education. As a result of this European research project, the tool was developed, tested and validated as a scoring rubric that covers three dimensions of capacities and skills: individual, interpersonal and networking (Penttilä & Kairisto-Mertanen, 2012, Marí-Benlloch et al., 2017, Lehto et al., 2011, Watts et al., 2013). It can be used for self-assessment, peer-assessment and also can be used by teachers as discussed above.

Later on, FINCODA, was developed adapting the INCODE Barometer to be used by companies and industry (Andreu-Andrés et al., 2017) as described above.

1.4. The pedagogy of engineering education: developing innovation competences

The traditional undergraduate engineering curriculum has been typically organized in two main blocks: during the first two years, instruction in basic sciences and mathematics, followed by two years of engineering sciences focus (Dym et al., 2005, Li et al., 2015). This traditional approach usually tends to be oriented to "intuitive, verbal, reflective and sequential learners" (Felder and Silverman, 1988; Felder and Brent, 2004). In this traditional approach, subject's information is given to students through presentations and lectures in a deductive manner, teaching principles first and then followed by its applications (Felder and Silverman, 1988).

As described by Saliklis et al. (2009), this way of teaching is typical for an engineering pedagogy, beginning with the lowest learning order (remember) of the Bloom's taxonomy (Krathwohl, 2002) and going upwards in the pyramid. Bloom's Taxonomy (1956) establishes a set of taxonomies in three domains of learning: cognitive, affective and psychomotor. The cognitive domain taxonomy is widely accepted in many fields as a language that describes the progressive development of an individual and to classify educational learning objectives into levels of complexity and specificity.

As opposed to traditional engineering education, in architecture education is usual to start with the highest part of the pyramid, getting the students to apply value judgments about the suitability of the design (evaluate) and making sense of disparate pieces of information (create), and solving large complex problems by breaking them down into smaller pieces (analyze). Also, integrated engineering curricula, like Industrial Engineering or Architecture in Spain, has traditionally taken care of these aspects through project subjects, but there was an identified lack of it in Information and Communications Technology (ICT) curricula (Sayrol et al., 2015).

Saliklis et al. (2009) use the original taxonomy from Bloom (1956), which involved synthesis and evaluation as the maximum levels of the cognitive domain described as Level 6: Evaluation, Level 5: Synthesis, Level 4: Analysis, Level 3: Application, Level 2: Comprehension, Level 1: Knowledge

In 2001, Anderson et al. published a revised taxonomy (Figure 6), pointing to a more dynamic conception of classification, describing the cognitive processes by which thinkers encounter and work with knowledge.

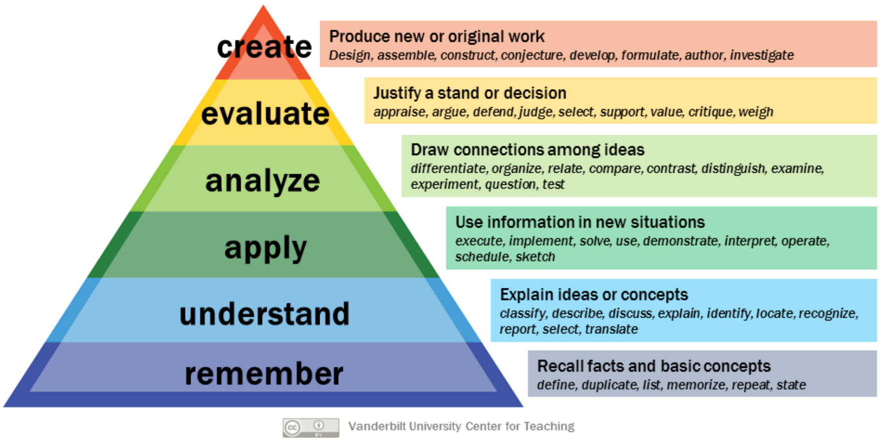


Figure 6: Bloom's Taxonomy, Source: Vanderbilt University Center for Teaching (revised version from 2001)

Engineering curricula have been based largely on an "engineering science" model over the last five decades, in which engineering is taught only after a solid basis in science and mathematics. This traditional engineering pedagogy approach works well for creating deeply analytic and technically skilled engineers, but also has led the industry to perceive graduates as "too theoretical", not being able to easily adapt to work due to this change from theoretical to practical. (Dym et al., 2005). This gap between academia and industry has been tackled through the creation of capstone design courses, allowing final year students to use their theoretical knowledge on a system level, working in "real" projects (Dym et al., 2005).

A capstone course or capstone project is a culminating and integrative experience of an educational program (Ford, 2002), where students apply what they have learnt in other courses into a project. As discussed by Alarcón et al. (2013), capstone projects are considered "to be enablers to engineering activity".

The majority of capstone courses use problem-based learning, putting the student at the center and the professor as a guide. Problem-based learning is an inductive approach, where the students discover the need or application before principles or tools are taught (Felder and Brent, 2004). Although this approach might daunt students, as it is opposed to the traditional deductive approach, it is aligned with the natural way people learn (Felder and Silverman, 1988).

Also, following Bloom's taxonomy, capstone courses achieve higher-level thinking, reaching the analyze, evaluate and create levels (Saliklis et al., 2009).

This method of working in projects based on problems in inherently experiential, aligned with Kolb's (1984) experiential learning cycle.

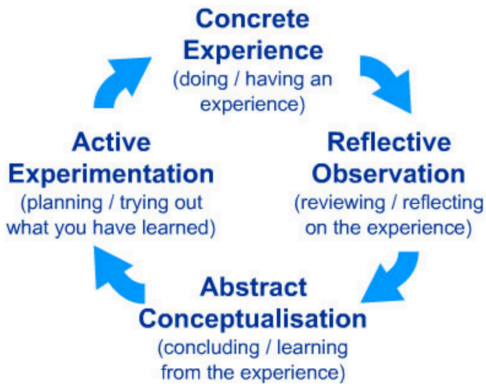


Figure 7. Kolb's experiential learning cycle (McLeod, 2017)

As described in Kolb's theory (Figure 7), effective learning occurs when a person goes through a four stages cycle: of (1) having a concrete experience, (2) observing and reflecting on that experience, that then leads to (3) the construction of abstract concepts (analysis) and generalizations (conclusions) which are then (4) used to test hypothesis in future situations, resulting in new experiences.

In Schön's (1987) influential book Educating the Reflective Practitioner, he argues that "professional education should be centered less on developing a specific set of skills in students and more on their ability to reflect first, then act in situations where established theories may not apply". The author also mentions that real-world problems in professional practice, do not present themselves to practitioners in a well-structured and defined manner. In fact, they present themselves as messy and indeterminate situations. The ability to "construct the problem" is the kind of skill addressed by the higher levels of Bloom's taxonomy.

The "ground-up" approach typically used in engineering, where first students learn the relevant basic science, then applied science and finally the put in practice in projects, where they are supposed to apply research-based knowledge to real life problems might not be the best approach (Schön, 1987).

Saliklis et al. (2009), as well as Schön (1987) believe that the approach used in architecture education, with the "design studio" that blends both art and science in a "learning-by-doing" experience might be particularly well suited for education of engineers. On the same line, Ledewitz (1985) argues that "all the aspects of design education- the skills, the language, and the approach to problems- are more effectively taught indirectly through experience than taught directly by explanation".

Design is a fundamental skill of engineering professionals and as a subject is been pushed to gain more presence in engineering curricula by ABET (2017). Similarly, in 1997 a report from the National Science Foundation called for a reform in engineering education emphasizing the need for: teamwork, project based learning and close interaction with industry (Dym et al. 2005).

Summarizing, the approach Dym et al. (2005) suggest can be synthetized in the sentence "beyond being the "capstone" of engineering education, design should be the very cornerstone of engineering learning". Teaching design and working in projects, going upwards in the Bloom's taxonomy, help the students develop some of the very much-needed skills of engineering professionals, as teamwork, making presentations and project management, among others.

1.5. Teaching innovation

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 et al., 2010). 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 required for innovation projects to be successful.

The main idea of applying an innovation pedagogy is to "bridge the gap between the educational context and working life" (Kairisto-Mertanen et al., 2012) which can be achieved through learning using active multidisciplinary methods. As Konst and Kairisto-Mertanen (2020) discuss, implementing an innovation pedagogy requires time, involvement of the whole educational community and management support and commitment. Also, as stated by Keinänen & Kairisto-Mertanen (2019), the learning environments associated with the innovation pedagogy are: activating teaching and learning methods, working life orientation, research, development and innovation (RDI) integration, multidisciplinary learning environments, flexible curricula, entrepreneurship and internationalization. All these have a direct relationship with students' innovation competences development (creativity, critical thinking, initiative, teamwork and networking). And as a result of their research, the authors state that "the more students have experience with learning environments of innovation pedagogy, the higher they scored when assessed for their innovation competences".

As discussed by Chell & Althayde (2009), trait theorist consider personality as something relatively stable and that behavior patterns, abilities and aptitudes are developed in early stages of life through the interaction of experience and genetic characteristics. This would mean that innovators are born (not taught). On the other hand, social cognitive theorists put greater weight on social learning. People mind-set is composed of knowledge, beliefs, attitudes, values formed in response to social contexts and influenced by emotions and feelings. Altogether, shape a person's behavior. The social cognitive approach considers that all the aforementioned may be learnt. Innovation is definitely a cognitive process, based on individual's experience and ability to create something valued by others (society, market,…) using its knowledge and ideas.

Fixson (2009) states that "If innovation is understood as a process of inventing and commercializing new products and services, as a process that incorporates activities from multiple disciplines, and as a process that follows more heuristic than algorithmic rules, then perhaps this process can be taught in an interdisciplinary setting with a strong experiential emphasis, such as product design and development". In the same line, Shuman et al. (2005) conclude that innovation skills can be taught but require a different modern education format using active and cooperative learning, incorporating real-world experiences into the engineering curriculum. Also, Chell & Althayde (2009) state that innovative behaviors may be learnt, and this learning should be based on experience and experimentation.

In conclusion, by an appropriate education strategy, training and experience, innovators may be developed through an experiential learning approach, where participants go through the key stages of the innovation process, moving from the concrete and abstract worlds (Beckman & Barry, 2007), in an environment with diverse teams.

The innovation process is composed of several activities coming from different fields of knowledge, typically taught in individual disciplines (for example, product development in engineering, commercialization in marketing, etc.). Similarly, the product development process comprises activities from several disciplines, like marketing, design, engineering, operations, management (Krishnan & Ulrich, 2001). In general, definitions of New Product Development (NPD) describe the following stages: opportunity identification, market and user research, ideation, conceptualization, refinement and selection, industrial design, engineering, prototyping, testing, financial analysis and market introduction (Fixson, 2009). In this process description, it is evident that knowledge and skills required for successful new product development go across multiple disciplines and fields of expertise. These disciplines are taught and organized in separate and specialized units, as deep expertise is required in any subject is needed. Experts of each discipline at specific stages of the process are required, but this approach is running short for today's extremely competitive markets. Having a holistic understanding and an integrated product/service innovation process, with experts from various disciplines in interdisciplinary teams is necessary.

In a more interconnected and complex work environment, with innovation challenges going way beyond purely technical aspects, having knowledge and expertise in an individual's own field is no longer enough (Oskam, 2009). It is needed to have basic knowledge and understanding of related/adjacent field to be able to collaborate both within and outside organizations.

Thus, it is mandatory to train innovation experts with what is known as the T-shaped approach, able to collaborate and co-create understating the overall picture and contributing from their specific area of expertise (engineering, design, marketing, business...). The concept of T-Shaped professionals, originally introduced by Kelley & Littman from IDEO (2005), refers to the type of profile required for dealing with this complexity. The T-Shaped professional has a deep knowledge in one field of expertise (the vertical axis of the T) and also a broad knowledge base with basic knowledge of adjacent/related fields or disciplines (the horizontal axis of the T). For example, this could be an engineer that has business knowledge or user experience acumen. This enables this type of professionals to effectively communicate with other disciplines and collaborate and with other project members. This is typically the profile of the Design Thinker (Brown, 2008). Thoring and Müller (2011) illustrate in Figure 8 the difference between these interdisciplinary experts vs. mono-disciplinary experts, where there is no interconnection between fields of expertise.

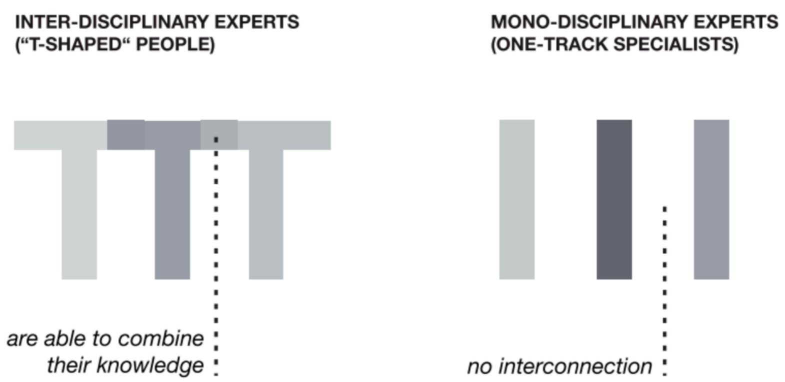


Figure 8. T-Shaped people vs. One-track experts (Thoring and Müller, 2011)

As discussed by Pippola et al. (2012), new courses aiming for creativity and innovativeness improvement in education have been created in schools and universities. Probably one of the highlights is the design engineering course at Stanford University ME310 (Carleton &

Leifer, 2009). This is in line with Elam et al. (2008), who state that to address the need for increasing innovation in United States, institutional educational strategies that leverage on the concepts of creativity, problem-solving principles, teamwork, critical thinking, among others are being developed.

Educational programs in engineering and technology have a great challenge, as they need to prepare students for jobs that today don't exist. Thus, they need to develop their curricula without knowing specific job requirements. Nevertheless, innovation, creativity and critical thinking will be part of any job. That is why teaching these abilities is fundamental for any university program, and specially engineering which need to cope with the fast advances of technology. Also, Fernandes et al. (2009) argue on favor of teaching structured methods and models for managing business innovation as a potent way to enhance innovation capabilities and to develop creative products. The process discussed is similar, if not the same that the one used for NPD (new product development)

In his study, Fixson (2009) describe three fundamental characteristics of programs to teach innovation: Interdisciplinary collaboration, experiential learning and performance assessment.

Interdisciplinary collaboration:

> Different examples are mentioned by the author with substantial differences between them. The Boston University (BU) undergraduate course in product development is actually a capstone-type course running in combination with four "traditional" courses in finance, operations, marketing and IT. This actually is a combination of four management sub-disciplines, thus not that interdisciplinary. On the contrary, the Babson College, Olin College of Engineering and Rhode Island School of Design merge business, engineering and industrial design students on a semester long joint teaching effort by the three institutions.
>
> More common are courses that combine two disciplines, normally business and engineering like the University of Minnesota and the University of Pennsylvania. Also, UPC and ESADE, combining engineering students and business students on innovation projects, run these types of courses like I2P course (Intensive Innovation Project) or even joint degrees, going beyond one course like the Bachelor's degree in Industrial Technologies and Economic Analysis (interuniversity UPC-UPF degree) by Pompeu Fabra University (UPF) and UPC Barcelona School of Industrial Engineering (ETSEIB).
>
> Team sizes for these projects range from 4 to 10 people, being 4 to 6 the most common number of members por project courses.

Experiential learning:

> Focus on "doing" and teamwork is the way for students to experience the process and learn as they develop the different activities.
>
> Due to the high degree of uncertainty inherent in innovation projects, active problem solving is a fundamental part of these courses. And as described by Fixson (2009), studio-style workshops in combination with lectures and cases discussion are the typical activities.
>
> Students engage in problem solving through user research to ideation and prototyping, working in all phases of the process with an experiential learning approach.

Most courses involve prototype development as part of the deliverables. This plays a fundamental role in the experiential learning, as students engage and discuss effectively working on a "real" solution that is tested in most cases with real stakeholders. Also, this helps to better communicate among students with different backgrounds.

Performance assessment:

Students' evaluations typically are composed of intermediate presentations and reports on the project progress, final presentations and prototype and final reports deliverables. Also, peer- and self-evaluations are required in many cases.

The course evaluation and value are demonstrated through project results, students' employability, press recognition, patents and venture launching by the students after the course. Also, these types of projects become a selling feature and great marketing tools for institutions, to attract prospective students.

One aspect that Fixson (2009) also highlights is the question of financial sustainability of these courses. They are resource intensive, involving faculty members from different disciplines, materials, tools and workshops, dedicated spaces. Some schools look for companies to sponsor specific projects or even fund entire courses. Some acquired dedicated spaces (NCSU, ASU, …). Northwestern University created a degree from their course, generating revenue from tuition.

Another interesting initiative to teach innovation is already discussed above, DEMOLA (2020), that was created as a cooperative effort of Hermia Ltd, Nokia Research Center (among other companies), universities and the city of Tampere (Finland). In this platform, students create product/service demo concepts in collaboration with companies in an atmosphere of creative co-creation and new learning opportunities.

The multidisciplinary teams of students own the rights of the creations and companies can purchase them or license the products from them. Also, DEMOLA creates spin off startups based on the innovations developed.

Now in the DEMOLA website https://www.demola.net/ , besides all the value of this open innovation initiative, it is also stressed the value for the companies of working with millennials. In the last years, millennials became a key target for companies, as they are there near future market (and current). From a marketing perspective this is a smart move, as now all industry is aiming to understand and develop products/services specifically addressing this collective, which behaves differently from other "traditional" targets (i.e. baby boomers, generation-x,…).

Using the DEMOLA platform in 2011, the University of Tampere (UTA), Tampere University of Applied Science (TAMK) and Tampere University of Technology (TUT) created the Innovation Project course.

The main objectives and learning goals of the Innovation Project are: multidisciplinary and multicultural teamwork, creation of a demo/prototype of a product, service or other innovation, understand project working practices, apply agile project management, apply design and research methods and presenting results orally and in writing.

Based on feedback obtained from students, the main learning experiences pointed out from DEMOLA projects are self-awareness of their own value as a team member (empowerment), multicultural collaboration and teamworking abilities, practical skills and working experience and entrepreneurial mindset.

In Table 10, Pippola et al. (2012) compare the Innovation Project course versus a traditional project course.

Attribute	Traditional project work course	Innovation Project course
Uncertainty, risk level	Moderate risk	High risk, high uncertainty
Scope	Defined	Defined
Mental focus	Processes, routines, execution	Substance, business
Main quality factors	Fulfilling customer needs, total quality of action, re-usability of results	Value and re-usability of concept, new possibilities – creative thinking, product potential
Relation to tradition, rules, thinking patterns	Follow rules, use heuristics	Break rules, think differently
Main reusable result	Product, documents	Idea, conclusion, principles
Lifecycle emphasis	All equally	Concept, fuzzy front end feasibility study, proof of concept, marketing
Working environment	Closed, homogeneous, one culture, team work alone	Open space, networking, heterogeneous, multicultural, international, all teams in one space
Communication	Inside team, rhythmic with teacher / long cycle	Inside team, between teams, short cycle with customer/partner, networking
Language	Native language	English
Product rights	Customer	Team
Skill set	Systematic project work, professional action, development & research methods, teamwork	Problem solving, teamwork, creativity, handling uncertainty
Learning experience	Project work, project management, how methods and theory work in practice, teamwork	Project work, team work, potential of creativity, intercultural working

Table 10. Comparison of traditional project work course vs Innovation Project course (Pippola et al., 2012)

Main conclusions of this comparison are that even that in both cases the scope is defined, in traditional projects the uncertainty and risk level is lower than in innovation project, which have high levels of uncertainty and risk. In innovation projects, the main quality factors are the value of the concept, new possibilities and creative thinking, while in traditional projects the value is in fulfilling customer needs and re-usability of results.

Innovation projects aim for breaking the rules and thinking differently, having as key results ideas, conclusions and principles. On the other hand, traditional projects follow the rules and use heuristics, having as key results products and documents.

One main difference is the product rights in DEMOLA projects, which in traditional projects belong to the client and in Innovation Project stay with the team of students.

The skills developed by students in Innovation Projects are more focused towards problem solving, teamwork, creativity and specially managing uncertainty. In traditional projects, these skills are oriented towards systematic project work, professional action, development and research methods and teamwork.

Regarding learning experience, traditional project work course highlight teamwork, project work, project management and understanding how methods and theory work in practice. In

Innovation Project course is similar regarding project work and teamwork but emphasizes the potential of creativity and intercultural working.

Once reviewed the innovation competences and the innovation pedagogy literature, a deeper focus on literature was sought to understand the different experiential learning methods for innovation education and the different innovation approaches. Summarized in Table 11 it is shown the framework for structuring the literature review around the main experiential learning methods for innovation education, that are basically active learning methodologies like Problem-based, Project-based and Challenge-based education. Also, these types of educational strategies usually follow two main approaches to innovation. The more "traditional" NPD (New product development) approach, following a traditional project-management process and the user-centered approach to innovation, Design Thinking.

In the following pages, a review and analysis of the literature around these topics is explained, as it helped to define the common ground of knowledge that served as the basis for developing the research framework.

Experiential learning methods for innovation education	**Innovation approach**
• Problem-based • Project-Based • Challenge-based	• NPD (New product development) • Design Thinking

Table 11. Experiential learning methods for innovation education and innovation approaches

1.6. Problem-based learning & Project-based learning

1.6.1. Problem-based learning

Freeland (1922) described problem and project-based learning, writing about their relatedness about both methods: "The problem is used to appeal to and develop the child's thought… The project may be defined in relation to the problem as something the child is interested in doing and which may involve thinking but need not always do so." Thus, it could be said that problems are embedded in project-based education. Douglass (1926) describes this by making a clear distinction: problems could be included in projects, and problems could become projects. Nevertheless, the principles and procedures for both project and problems are in essence, the same.

Problem-based learning, as we know it today in higher education, evolved from medical education practices introduced in North America in the 60', at McMaster University (Canada) and later on at Harvard (United States). This philosophy was then spread worldwide in many professional fields by the 80's. Also, it expanded to elementary schools, middle schools, universities, and professional schools (Torp & Sage, 2002)

The skills developed through problem-based learning include critical thinking, complex and real-world problem solving, to identify and utilize learning resources, cooperative work, communication skills and becoming a continual learner (Duch et al., 2001).

Also, Barrows (1994) summarizes problem-based learning characteristics:

- Learning responsibility is on the student
- Problems must be ill-structured and allow free inquiry
- Several subjects or disciplines must be integrated on learning
- Collaboration is fundamental
- Discussion of concepts learnt are essential
- Self and peer evaluation
- Link to real world valued activities

This is still very relevant, and specifically in engineering education, as mentioned by ABET in 2017, which defined as fundamental learning outcomes for any engineering program the following abilities: "identify, formulate and solve engineering problems".

Jonassen and Hung (2008) define the different types of problems and analyze their roots and characteristics, coming from the level of difficulty and nature of the problems.

Wood (1983) described problem difficulty as "a gauge of how likely the problem is going to be solved correctly or appropriately" and it is also determined by the size of the problem space (Kotovsky et al., 1985). Also, Wood (1983) defined structuredness of a problem as the degree to which the "ideas in the problem are known or knowable to the problem solver".

As observed in Table 12 in Jonassen & Hung's (2008) theory, there are two dimensions of problem difficulty: Complexity and structuredness. Complexity is based on Breadth of knowledge required to solve the problem, Attainment level of domain knowledge, Intricacy of problem-solution procedures and Relational complexity. Structuredness is defined by Intransparency, Heterogeneity of interpretations, Interdisciplinarity, Dynamicity and Legitimacy of competing alternatives.

Complexity	Structuredness
Breadth of knowledge required to solve the problem The level of knowledge on the domain does it is needed to solve the problem	**Intransparency** How much we don't know about the problem space. The more we don't know, the more ill structured.
Attainment level of domain knowledge The level of difficulty of the concepts needed to apply to solve the problem (Kotovsky et al. 1985)	**Heterogeneity of interpretations** How many interpretations and viewpoints exist to understand and solve the problem.
Intricacy of problem-solution procedures The intricacy of the problem-solution process or the length of the path to the solution (Hays & Simon, 1974)	**Interdisciplinarity** When interdisciplinary knowledge is needed it is key to identify all faces (disciplines) and their interdependencies.
Relational complexity Cognitive load, as the number of relations needed to process in parallel during the process of solving the problem (Halford et al. 1998)	**Dynamicity** Dynamic variables affect greatly to increase the ill-structuredness of problems.
	Legitimacy of competing alternatives The number of possible options of solution paths. This increases uncertainty of confidence on choosing the solution to the problem and the effort (time and tasks) to validate the options of solutions.

Table 12. Dimensions of problem difficulty (Jonassen & Hung, 2008)

Jonassen and Hung (2008) summarize in four the amendable types for problem-based learning:

Diagnosis-solution problems

> Usually begins analyzing symptoms of a person (patient) or system, having a pretty clear objective (patient's health state is reestablished, machine is fixed,…). But they also have a quite high level of intransparency and heterogeneity of interpretations (causes can be multiple).

Decision-making problems

> These types of problems require selecting an option from a number of different possible solutions. Many times, they are a continuation of diagnosis-solution problems. The latter focuses on identifying the causes of the problem, then decision-making is oriented to identifying the most suitable solution for the problem.

Situated cases/Policy problems

> Typically, complex and multifaceted, and in many cases the difficulty is that is not clear what the problem is. Being vague, ambiguous and highly intransparent, these types of problems are typical in professional situations (international relations, managerial problems, business, …). Necessarily interdisciplinary, needing to

accommodate economic, political, religious and social factors among others. Justifying decisions is one of the key aspects when solving this type of problems.

Design problems

According to Jonassen (2000), design problems are the most complex and ill structured type of problems. They typically have unclearly defined goals, wide range of solutions, different solution paths and not clear constraints. Also, what make them even more ill structured is the varying criteria for evaluating solutions, which are subjective, vary over time or are not known until the end of the design process.

Atman et al. (2007) have demonstrated that experienced designers tackle design problems dedicating more time to scoping the problem and researching information than students.

Also, as shown in Figure 9, according to Jonassen (2000), there are ten types of problem typologies.

Algorithmic problems

Story (word) problems

Rule-using/rule induction problems

Decision-making problems

Troubleshooting problems

Diagnosis-solution problems

Strategic performance problems

Situated cases/Policy analysis problems

Design problems

Dilemmas

Well-structured ↕ **Ill-structured**

Figure 9. Typology of problem types (Jonassen, 2000)

1.6.2. Project-based learning

The roots of project-based learning could be found back around one century ago, when the educator and philosopher John Dewey (1959) worked at the Laboratory School at the University of Chicago basing his work on the process of inquiry. Dewey argued that this inquiry process and engaging in meaningful tasks and problems would deeper understanding.

According to Knoll (1997) the "project" as method of institutionalized instruction was born within the architectural and engineering education movement in Italy during 16th century.

When defining what a project is, Kilpatrick (1921) describes it as "any unit of purposeful experience, any instance of purposeful activity where the dominating purpose, as an inner urge, (1) fixes the aim of the action, (2) guides its process, and (3) furnishes its drive, its inner motivation."

As described by Krajcik & Blumenfeld (2006), Blumenfeld et al. (2000) and Krajcik et al. (1994), project-based learning is "an overall approach to the design of learning environments". It is based on the "constructivist finding that students gain a deeper understanding of material when they actively construct their understanding by working with and using ideas."

These authors describe the key five characteristics of these learning environments as:

1. Starting with a driving question (the problem)
2. Students engage in an inquiry process, learning as they explore this driving question
3. Students, teachers and community engage in collaborative activities to find solutions to the problem
4. Through the inquiry process, students leverage on learning technologies that allow them to take part in activities that go beyond their ability.
5. As a result, students create tangible solutions (artifacts) that solve the driving question that are representations of the class's learning.

When applying these principles of project-based learning in engineering higher education, Cazorla & De los Ríos (1996) describe their strategy from the idea of active learning process with learning by doing approach (Bartkus, 2001; Hackett et al., 1998; Johnson, 1999), where the students learn from reality, where they extract relevant knowledge. They mention the importance of leaving the classroom and giving the students the chance to work on problems directly with real stakeholders. They also complement these activities within the course with lectures, group activities in class and participatory workshops.

After a 20 years' experience of project-based learning, Cazorla et al. (2007) present it as the "most adequate educational methodology for the development of competences, linking teaching with the professional sphere". This learning process requires an active role, both from students and teachers, and greater responsibility in their own learning on the students. They are not passively receiving knowledge, but rather they generate it through their immersion in a pre-professional practice.

After testing this methodology in such a period of time, the authors state that "elements of personal competences are also developed: teamwork, communication, leadership, commitment and motivation, self-control, self-confidence, openness, creativity, outcome orientation, efficiency, values, and the capacity for adaptation and innovation in problem solving" (Cazorla et al., 2007; De los Ríos et al., 2006). They also mention that this methodology creates and encourages the spirit of innovation, research, creativity and motivation.

1.6.3. Comparing Case, Project and Problem-based

Savery (2006) makes a comparison between case-based learning, project-based learning and problem-based learning highlighting the main similarities and differences. As well as case-based learning, project-based learning promotes active learning and encourages students in higher-order thinking (analysis and synthesis).

In case-based learning, students get to know and understand the key aspects of a problem (case) to be better prepared to face similar situations in the future. Students develop critical thinking analyzing the case study, develop knowledge and specific terminology and understand the relationships between the elements provided in the case. Also, when case studies are done in groups, students may improve their communication and collaboration abilities.

Project-based learning and problem-based learning are alike in that the learning activities are structured towards achieving a common objective (project). Typically, in project-based learning, learners are given a set of specifications for a desired output or end product (create an App for X, build a device to measure Y,…). In this approach, "the learning process is more oriented to following the correct procedures". Professors have more a role of a coach or instructor (rather than a tutor), providing guidance, feedback and recommendations to guide the students to reach the final outcome/product. Teaching is provided based on student's needs and within the project context. Like in case-based learning, students add this new experience to their memory that will help them when facing future similar situations.

Savery (2006) states that both case and project-based learning are excellent educational strategies, but they tend to diminish student's role in setting the goals and outcomes for the "problem". When the results (outcome) are clearly specified, there is less need or motivation for the student to setting his own parameters.

Both inquiry-based learning and problem-based learning are grounded in the philosophy of John Dewey, who stated that learning starts with the curiosity of the student. Both approaches are student-centered, imply active learning based on questioning, critical thinking and problem solving. They start with a question and create new knowledge as students investigate solutions, gather information and understand it, discussing experiences and findings, and reflecting on this newly acquired knowledge.

The main difference of problem-based learning is the role of the tutor, which in other approaches is both a facilitator of learning and provider of information. In problem-based learning, the role of the tutor is more oriented to supporting the process, expecting the student make their thinking clear, but not providing information about the problem, that is on the accountability of the students.

When discussing engineering education, Mills & Treagust (2003) compare also problem-based education vs. project-based education. They argue that still, since 1950's the predominant engineering education model is still "chalk and talk" (single-discipline and lecture-based) during the first years of study. This does not promote communication and teamwork skills, nor give a broader perspective beyond technical knowledge (i.e., social, economic or environmental issues).

These authors highlight the critical issues to be addressed in engineering, and that these could be tackled through problem-based education. The main issues described are:

- Programs are content driven, too focused on engineering science and technical skills, not enough integrated or related with industrial practice.
- Not providing enough design experience to students
- Lack of communication skills and teamwork training
- Awareness of social, environmental, economic and legal aspects of real today's engineering practice not addressed
- Many faculties lack practical experience, not being able to relate practice and theory
- Teaching and learning culture need to become student-centered

Although there are examples using problem-based education in engineering, Perrenet et al. (2000) conclude that it has limitations that make it less adequate as an overall strategy for engineering education. One of these limitations is the constructivist philosophy behind project-based learning. Engineers, during their professional life must be able to apply concepts learnt at university to solve problems outside of their experience in class. Of course, every problem they will face will almost certainly be different from those they experienced at university. “Findings from research on misconceptions suggest that problem-based may not always lead to constructing the ‘right’ knowledge” (Perrenet et al., 2000). Thus, problem-based learning might not be always useful for engineering education regarding “the acquisition of knowledge that can be retrieved and used in a professional setting”. As opposed to medical education (where problem-based education has been used since 1960’s), that has a rather “encyclopedic structure”, engineering has a more hierarchical structure. Many topics need a certain order of learning; otherwise, missing concepts will end up in failure to learn later concepts. Thus, “the issue of the particular hierarchical knowledge structure of much of engineering is possibly the most fundamental obstacle for implementation of problem-based engineering through an entire engineering program, as opposed to within individual courses in the program” (Mills & Treagust, 2003).

Due to these issues, it seems that project-based learning, that is also a student-centered and active learning approach that mirrors the professional practice of engineering seems more adequate.

As described by Perrenet et al. (2000), project-based learning and problem-based learning outcomes have many similarities, although they found some differences as seen in Table 13.

Similarities	**Differences**
Based on self-direction	Project-based tasks are closer to reality, taking longer periods of time than problem-based learning problems.
Collaborative	Project-based: more oriented to applying knowledge Problem-based: more directed to acquiring knowledge
Multidisciplinary	Project-based is normally accompanied by subject courses (mathematics, physics…) while problem-based is not.
	Student’s time & resources management is more important in project-based. Self-direction is more relevant also in project work.

Table 13. Project-based learning and Problem-based learning outcomes (Perrenet et al., 2000)

1.6.4. Project-oriented Problem-based learning

Capraro et al. (2013), when describing project-based learning for STEM (Science, Technology, Engineering and Mathematics) talk about two important concepts for this type of courses: well-defined outcome and ill-defined task.

Normally, engineers start with a clear end in mind (e.g. reduce fuel consumption, communicate a signal, support this weight, ...). Based on this, Capraro et al. (2013) define his STEM PBL (project-based learning) design process as “always begins with a measurable object in mind”. This is a well-defined outcome.

On the other hand, the authors explain that ill-defined tasks are essential to the research process. This requires in STEM PBL a higher order of thinking skills, problem-solving and improved content learning. Ill-defined is not ill-designed, as professors design the process to allow student's research, a wide range of solutions to converge in a common understanding of the outcome.

They define STEM PBL as "an ill-defined task within a well-defined outcome situated with a contextually rich task requiring students to solve several problems… The ill-defined task allows students the freedom to interpret the problem, constraints, and criteria informed by their subject area knowledge to formulate diverse solutions that will meet the well- defined outcome"

Nevertheless, today's systems and problems are progressively larger and more complex, with often difficult to define borders. As stated by Lehman et al. (2008), "societal, rather than technical issues play bigger roles. Problems cannot be solved by applying a technical solution alone". It is fundamental for professionals to be prepared not only in terms of their technical fields, but also to identify non-technical aspects of problems to address.

Being part of a global society, engineers today must deal with dissimilar capabilities, going beyond their technical skills related to problem solving. They need to have interdisciplinary skills for cooperation, communication skills, project management abilities and life-long learning abilities (Lehman et al., 2008). These authors suggest that problem-oriented and project-based learning as the answer to the challenges engineering education faces, mentioning the Aalborg Model as a reference.

However, getting to this cross-disciplinary and contextual knowledge, integrating comprehension and skills from diverse disciplines is challenging and require innovative ways to approach education.

Similar to ABET in the United States, in Europe the EUR-ACE (Accreditation of European Engineering Programmes and Graduates), expectations for engineering graduates go beyond the purely technical skills. This has shifted (or is shifting) educational strategies from the traditional paradigm with a discipline-oriented, lecture-centric and technical knowledge-based to a new interdisciplinary, student-centric and contextualized, with a complex understanding of technological knowledge. This is the Denmark example, with Aalborg as a reference.

Lehmann et al. (2008) summarizes this approach as POPBL (project oriented problem based learning), synthetizing the knowledge and competencies of this approach in Table 14:

POPBL principles	**Knowledge and competencies gained**
Cognitive learning	Problem-solving Project management Contextual analysis
Contents	Subject knowledge Technical skills Cross-disciplinary knowledge Knowledge management
Collaborative learning	Collaboration Communication (oral and written) Project management and planning

Table 14. Knowledge and competencies achieved through POPBL approach (Lehmann et al., 2008)

The shift from teaching to learning is probably the most relevant and innovative aspect of this educational approach, where the role of the professor changes from "transferring knowledge into facilitating the learning process of the students" (Kolmos 2006).

Kolmos and De Graff (2003, 2007) synthetize the 3 key learning principles in three approaches (Figure 10):

1. Cognitive learning: learning is structured around problems and is developed through projects
2. Contents: focused on interdisciplinary learning, (as opposed to traditional subject-related) and supporting the relationship between theory and practice.
3. Social approach: team-based learning, as a social act where learning takes place through conversation and communication.

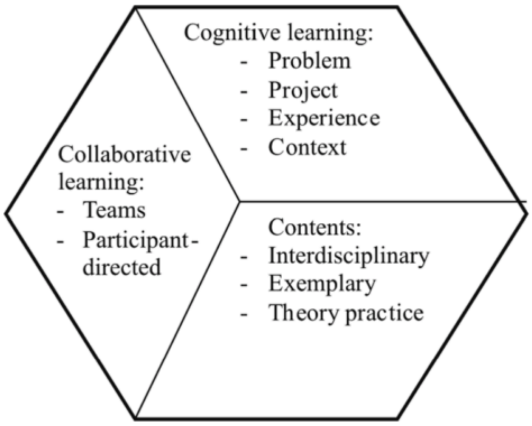


Figure 10. Learning principles in Project Based Learning (Lehman et al. 2008, based on the work from the work of De Graaff & Kolmos 2003, Kolmos & De Graaff 2007)

In reality, the closest to a completely project-organized program is the Aalborg's University in Denmark, where projects and project-related courses are about 75% of the program.

1.6.5. The University of Aalborg case

The University of Aalborg, Denmark was founded in 1974 with the pedagogic premise of project-based learning (Kjersdam and Enemark, 1994; Luxhol and Hansen, 1996). The Aalborg vision was "Problem-Oriented, Project-Organized, Learning"

As described by these authors, and synthetized by Dym et al. (2005) the premise of Aalborg is that by nature, project-organized education is multidisciplinary and can be distributed in two main topics, similar to the concept of divergent and convergent thinking:

- "Design-Oriented: project-organized education deals with know-how, the practical problems of constructing and designing on the basis of a synthesis of knowledge from many disciplines
- Problem-oriented: project-organized education deals with know why, the solution of theoretical problems through the use of any relevant knowledge, whatever discipline the knowledge derives from."

20 years after its foundation, the University conducted a research (Christophersen et al., 1994) to assess the performance of their graduates. Three of the main highlights of this report were:

•For newly entrants engineering students, project work involvement is not seen as effective as it may, due to students lack technical knowledge to fully benefit from the experience. Nevertheless, this is balanced with the benefit of establishing a group culture (teamwork).

•The quality of the work conducted by Aalborg students in their capstone projects (thesis) were of a quality equivalent to students from universities Aalborg is competing to internationally

•According to the employers engineering graduates, there were no differences in the general competencies between of Aalborg's engineers and other universities graduates. Nevertheless, graduates from Aalborg were evaluated as having remarkably better skills in cooperation.

In conclusion, project-based learning, in combination with some traditionally taught courses seems the best way to train future engineers with the needs and demands from industry, without compromising knowledge of engineering fundamentals.

1.6.6. The CDIO Initiative

In the same context as Dym et al. (2005) and Dym (1999) describe, aimed at bridging the perceived gap between the industry and engineering graduates, is where the CDIO (Crawley et al., 2011) initiative is grounded. With the objective of addressing industry demands towards engineering education, the CDIO (Conceive-Design-Implement-Operate).

CDIO proposes a kind of back to the roots in teaching engineering practice, which in the programs throughout the 20th century was very common with a lot of hands-on practice. With the rapid expansion of scientific and technical knowledge, the engineering practice teaching was de-emphasized, and focus shifted from solving tangible problems to teaching engineering science.

This resulted in industry finding graduating students technically proficient but lacking many skills required in real-world engineering practice.

The result of this is the worldwide CDIO initiative, created by recognized engineering schools around the globe (USA, Europe, Africa, Asia, Oceania), to design and develop a new vision of engineering education.

The CDIO initiative's vision is that "engineering graduates should be able to: Conceive – Design — Implement — Operate complex value-added engineering systems in a modern team-based engineering environment to create systems and products."

The main tools provided by the CDIO initiative to the engineering education are the CDIO Syllabus 2.0, a comprehensive list of skills compatible with the ABET requirements and a set of twelve standards to help universities implementing courses to develop these skills in the engineering graduates. Two of the CDIO-standards are to have programs with design-build-test projects (Standard 5: Design-Implement Experiences) and to promote active and experiential learning (STANDARD 7: Integrated Learning Experiences and STANDARD 8: Active Learning).

This framework allows giving the students an education focusing on Conceiving-Designing-Implementing-Operating (CDIO) real-life systems and products.

Lately, also there were initiatives based on this paradigm shift, going beyond the traditional engineering skills, teaching through project-based interdisciplinary experiences creative thinking, very much needed in modern engineering education (Wu & Wu, 2020). These authors focused on developing students' innovative thinking and ability to solve engineering problems through the design of creativity courses that foster students' creativity and critical thinking.

1.6.7. The back-to-basics theory

Despite all the bibliography and evidence related to the benefits of problem-based and project-based education, there are authors contradicting this approach and proposing a "back to basics" strategy. Brito et al. (2017) criticize the "neglecting" of the classical approach, stating that it could the more useful for the demands of today's job market.

They characterize the classical approach as "solid basis of knowledge in basic sciences and basic sciences of engineering". They argue that for this rapid changing world, the lifespan of specific knowledge learnt by students will be too short. Thus, those with general education will develop adaptive skills that will serve them to keep up to date with an evolving world. They propose the classical approach, with a strong focus on mathematics as the best strategy for institutions to train the students for this fast-changing professional world.

They agree on the diagnostics and the needs of the future engineering graduate, but definitely the interdisciplinary, contextualized and collaborative aspects broadly described above will not be addressed with the classical approach. It is of course needed (and expected) a solid base of technical skills in engineers, but for the evolving complex challenges of today and the future, it is not enough.

Although project-based learning is becoming the standard for developing key innovation competences in engineering students like teamwork, communication, project management and real industry interaction, there are innovation competences that are not covered or could be improved like multidisciplinarity, creativity and dealing with uncertainty among others. Also, the complexity of the societal challenges that we are facing as a society, synthetized for example with the United Nations SDG (Sustainable Development Goals, 2015), lead to a need for a broader approach and an evolution of project-based and problem-based learning. In the last years, challenge-based learning emerged as an innovative learning approach that tackles higher education from a broader perspective.

1.7. Challenge-based learning

Traditional educational strategies are becoming more and more ineffective with a generation of young students with instant access to information, that are content producers and publishers, with extensive access to social networks online. This happens not only with high school students, but also with university students.

Old high school curriculums presented the assignments with a disconnection from real-world context, leading to uninspired projects ending in a grade or score. The engagement of students become a fundamental aspect of education. To tackle this, Apple, the famous company from Cupertino, California, developed since the 80's a research and development cooperation with public schools, research agencies and universities called Apple Classrooms of Tomorrow (ACOT) and Apple Classrooms of Tomorrow Today (ACOT2).

This research focused on the effects and possibilities of the technology in education, to enhance learning in primary school and high school, as described in the document from the company "Apple Classrooms of Tomorrow-Today" (2008) and on the website www.appleclassrooms.com. ACOT2 was oriented to explore the impact on the traditional model of schooling by the access to internet and mobile devices, with the aim of identifying the essential design principles of the learning environments of the 21st century. As a result of this collaboration, they developed the concept of Challenge Based Learning.

The Challenge Based Learning framework is "collaborative and hands-on, asking all participants (students, teachers, families, and community members) to identify Big Ideas, ask good questions, identify and solve Challenges, gain in-depth subject area knowledge, develop 21st-century skills, and share their thoughts with the world". It is an engaging multidisciplinary approach to education (teaching and learning) that encourage students to use the technology they use in their daily life to tackle real-world problems.

It is hands-on and collaborative, and students work with peers, teachers, and experts in their communities to create solutions to these real-life universal problems.

The attributes of Challenge Based Learning, as described by Nichols & Cator (2008) are:

- A multiple entry point strategy and varied and multiple possible solutions
- A focus on universal challenges with local solutions
- An authentic connection with multiple disciplines
- An opportunity to develop 21st century skills
- The purposeful use of Web 2.0 tools for organizing, collaborating, and publishing
- The opportunity for students to do something rather than just learn about something
- The documentation of the learning experience from challenge to solution
- 24/7 access to up-to-date technology tools and resources so students can do their work

These attributes, as stated by the authors, enable Challenge Based Learning to engage students providing them valuable skills, blur the divide between formal and informal learning while embrace student's digital life.

As observed in Figure 11, the framework of Challenge Based Learning starts with a Big Idea, that then develops an Essential question and a challenge definition. After that, comes the guiding questions, activities, resources, that help to determine and articulate the solution and taking action by implementing the solution. Finally, it comes the reflection, assessment, and publishing of the results to the world.

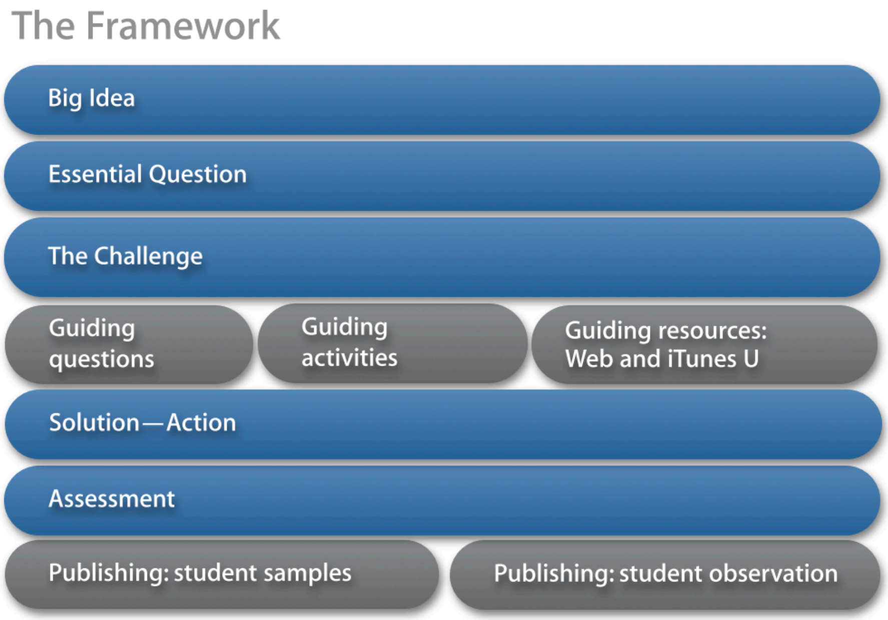


Figure 11. Challenge Based Learning Framework (Nichols & Cator, 2008)

The process of Challenge Based Learning mimics in its workflow the 21st century workplace. Learners have enough space for creativity and self-direction, while at the same time are given support, boundaries and checkpoints to avoid frustration. The authors explicitly mention that this workflow summarized in the framework is flexible and can be structured and modified, being just a starting point and not meant to be prescriptive.

Figure 12. Challenge Based Learning Phases (www.challengebasedlearning.org, 2018)

Engage, Investigate and Act are the three Challenge Based Learning framework interconnected phases (Figure 12). As shown in Table 15, within each phase there are specific activities that help the students to develop their projects and move to the next phase.

Within each phase, there are iterative investigation cycles, meaning that when necessary can return to previous phases. During the whole process, there is an ongoing documentation, reflection and sharing.

ENGAGE	INVESTIGATE	ACT
Moving from an abstract idea to a concrete actionable through the Essential Questioning process. The objective is making the students personally connect with academic content by identifying, developing and owning a compelling challenge.	Through a contextualized learning experience, students conduct rigorous, content and concept-based research to develop the foundations for actionable and sustainable solutions.	Evidence-based solutions are developed and implemented by students for a real audience, and the results are evaluated. Students combine the desire to make a difference and a demonstration of contents knowledge.

Table 15, Challenge Based Learning phases description of activities (Nichols & Cator, 2008)

Although the previous was developed for primary and secondary school education in mind, the same approach can be applied to higher education. Several authors describe the concept of Challenge Based learning and experiences in higher education, and specifically in engineering education.

1.7.1. Challenge-based learning in higher education

Challenge-based learning, as defined by Malmqvist et al. (2015) is "a learning experience where the learning takes places through the identification, analysis and design of a solution to a sociotechnical problem. The learning experience is typically multidisciplinary, takes place in an international context and aims to find a collaboratively developed solution, which is environmentally, socially and economically sustainable". It could be seen as an evolution of problem-based learning but with a few differences, like starting with large open-ended problems, training of self-awareness and self-leadership and entrepreneurial mind-set, among others.

Similarly, Johnson et al. (2009) say that "a new teaching model is required, that takes the best of problem-based learning, project-based learning and contextual teaching and learning while focusing on real problems face in the real world", and they state that that model is challenge-based learning. This model allows giving the students the chance to work collaboratively on real and relevant problems, engaging their curiosity and eager to learn, managing their own time, with the teacher as supportive guides. The unique idea of challenge-based learning is that problems are relevant and with global importance, related to sustainability, water, energy, poverty, etc. Also, a differential aspect is the "call to action" that goes beyond the classroom, aiming the students to have an impact on the society with their projects.

Unfortunately, and despite of its real contribution to education, it has become also a buzzword in the past years, having experiences that are simple projects (technical projects) being also called challenge-based learning. As an example, Willis et al. (2017) mention "whether they are called hackathons, competitions, code-a-thons, or design projects, activities that challenge students of all ages to solve difficult problems can serve as a powerful tool for education and engagement". Indeed, these activities foster technical skills and soft skills, like teamwork and communication. Nevertheless, as discussed above, challenge-based learning tackles societal problems and go beyond solving purely technical problems.

In 2008, the NAE (National Academy of Engineering) in the United States identified what are called the "grand challenges" for the 21st century for engineering summarized in Table 16. These challenges are structured in four categories: Sustainability, Security, Health & Joy of living.

Sustainability	**Security**	**Health**	**Joy of living**
1. Make solar energy economical 2. Manage the nitrogen cycle 3. Provide energy from fusion 4. Develop carbon sequestration methods 5. Restore and improve the urban infrastructure	6. Secure cyberspace 7. Prevent nuclear terror	8. Advanced health informatics 9. Engineering better medicines 10. Reverse engineer the brain 11. Provide access to clean water	12. Advance personal learning 13. Enhance virtual reality 14. Engineer the tools of scientific discovery

Table 16. 14 Grand Challenges for Engineering in the 21st Century (NAE, 2008)

These Grand Challenges are on the same line of thought of the United Nations (UN) Sustainable Development Goals (Figure 13) adopted in 2015 but focusing on engineering and with a more technical approach.

Figure 13. SDG - Sustainable Development Goals (United Nations / UN, 2015)

UN sustainable development goals (SDG) clearly state the vision on the aspects that we, as a society must face in the following years. It is interesting to mention that among the 17 goals there is one that specifically mentions innovation (9. Industry, Innovation & Infrastructure). Nevertheless, it could be said that to tackle all challenges what we need is innovation. We need to develop new strategies, new ways of collaboration, and new paths for research. We need to create innovative solutions and approaches to achieve these goals, and through challenge-based learning students could be better prepared to face this.

The concept of the "grand challenges" became popular over the last decade and is progressively adopted by governments and academia, approaching research and innovation problems as challenges. An example is the VINNOVA (https://www.vinnova.se/en/) program from the Swedish agency for innovation. Another example is the www.grandchallenges.org (2021), a family of initiatives fostering innovation to solve key global health and development problems. Each initiative is an experiment in the use of challenges to focus innovation on making an impact.

VINNOVA, the Innovation Agency from the Swedish government, manages challenge-based research and innovation programs around five prioritized areas: industry and materials, circular and bio-based economy, smart cities, life science and travel and transport (Vinnova, 2018). They state that challenges are "international, multidisciplinary, pertain to environmental, social and/or economic sustainability and therefore cannot be solved by a single actor" (Malmqvist et al., 2015)

The approach from VINNOVA (2017) focuses on turning these challenges (climate, energy, demographics, security, health, education…) into opportunities. They represent a serious threat for the future of our societies, but they also constitute an opportunity and a demand for innovative solutions to these problems and to create growth. Traditional inventions within specific research fields will not solve these challenges. They aim for shifting the focus from silo thinking to multidisciplinary and cooperative work between different research fields, private and public sector, policies… In 2011 they launched the Challenge-Driven Innovation program to foster that, with the objective of delivering real innovation to tackle societal challenges.

The program supports projects with funding and also running different activities like workshops focusing on methods, practical hints and leadership. Projects supported have a comprehensive approach (where technology is just one aspect), broad stakeholders, and users and customers are key players and have a strong focus on applicability of the solutions. These projects must be based on key societal and industry needs, deliver real innovation with international business potential as well as benefit the community.

To address these types of challenges it is needed to deal with uncertainty and ambiguity, work with different stakeholders with diverse objectives, different technologies, understanding the long-term consequences of the proposed solutions and of course, technical knowledge of specific disciplines.

The concept of wicked-problems is similar in many ways to challenge-based problem setting. Defined by Rittel and Weber (1973), in wicked problems is "less apparent where problem centers lie, and less apparent where and how we should intervene even if we do happen to know what aims we seek". Similarly, Lönngren (2014) describe five key aspects of wicked sustainability problems:

- Problem understanding and solution understanding cannot be separated

- There are always many different ways to solving the problem, not a single solution
- Solutions might work at some point in time, but could be very problematic at another
- Context is fundamental and each problem is new and unique in that specific context
- Each problem would raise competing different interests and objectives from different value systems and stakeholders

Although these characteristics defined by Lönngren are focused on sustainability, they are easily translated into any kind of wicked problem or complex challenge.

We can locate the roots for challenge-based learning in problem-based learning, having mainly similar characteristics. In both cases, students (teams) are asked to address a "problem" (design, research, diagnostic…) and the learning experience takes place through working towards the solution. Nevertheless, challenge-based learning has a greater degree of difficulty or complexity of the problem as they focus on "societal challenges". These are inherently multidisciplinary but not knowing upfront (before project starts) which disciplines might be required. Also, in challenge-based learning it is often stated that solutions not only have to be proposed, they have to be implemented. Moreover, these learning experiences combine addressing societal goals with business development, going beyond the technical solution, but also proposing a viable business model/business development strategy.

Malmqvist es al. (2015) and Rådberg et al. (2020) summarizes the evolution of engineering education from traditional to problem-based to challenge-based (Table 17), considering that despite the transformation in all cases they are all based on a rigorous covering of engineering fundamentals.

	Traditional	**Problem-based / CDIO**	**Challenge-based**
Disciplines involved	Engineering science	Engineering	Engineering & business
Context	R&D context	Product design context	Societal context
Main activities developed	Analyzing	Designing	Problem formulating & Designing
Working model	Reductionist Individual	Integrative Team	Integrative Team & Individual
Main focus	Objective	Customer needs	Value-driven

Table 17. Evolution of engineering education from traditional to problem-based to challenge-based (Malmqvist et al., 2015)

1.7.2. Experiences of challenge-based learning (cases)

There are initiatives of challenge-based learning being applied in education at different levels, from bachelor to masters discussed by Malmqvist et al., 2015, synthetized in Table 18 and described below:

University of Western Australia – Global Challenges in Engineering

The course "Global Challenges in Engineering" (Baillie et al., 2014) is taught on the first year of Civil Engineering. Students work on a real project in collaboration with an NGO and the focus is typically poverty and waste problems.

The expected learning outcomes are "communication, enquiry & literacy, teamwork & project management, cultural and gender diversity, critical thinking related to environmental, legal, ethical, health and safety impacts of engineering, environmental, social and economic context in which engineering is practice, and design processes including creative thinking, evaluation, failure modes assessment" (Malmqvist et al. 2015)

The course runs for 13 weeks, having one lecture/information session and one workshop/teamwork session weekly.

The assessment is based on attendance to workshops, reports of weekly progress, project proposal, and final project report with oral presentation.

Being at the first year, it has the role of setting the scene for the entire program and introducing a wide-ranging view of the engineering profession.

Purdue University – EPICS program

Since 1995 the EPICS program (Engineering Projects in Community Service) has been active in Purdue University in United States (EPICS Purdue, 2018).

It consists of a framework through which multidisciplinary undergraduate students' teams work on projects to "design, build, and deploy real systems to solve engineering-based problems for local community service and education organizations". The main idea of EPICS is to bring community service agencies in need for specific technical solutions to work with students, with the objective of developing design, communication and collaboration skills.

The learning outcomes of EPICS include "design-build-test skills, teamwork and communication, project planning & leadership, customer-awareness and understanding of ethical, economic, and legal issues" (Malmqvist et al. 2015).

The course has weekly lectures during one term and has structured weekly deliverables. Nevertheless, not all type of projects could be considered challenge-based, as there are many that are purely technical issues to be solved rather than societal challenges.

DTU (Technical University of Denmark) – Green Challenge

The Green Challenge from the Technical University of Denmark aims to promote green designs through a competition. This competition incentivizes the students to tackle environmental problems with ambitious and visionary solutions but also aiming for implementation. The competition has different categories (bachelor thesis, master thesis and other projects). It has cash prizes, but also gives access to events that allow students to get in contact with companies interested in green business development and also with researchers.

The assessment is based on project presentation, environmental/energy impact of the project, technical viability and innovativeness.

As it is not part of a program or class, the Green Challenge has a minimum of taught topics, but it does have some lectures on how to carry an "innovation pitch".

Chalmers University of Technology - Challenge Lab (C-Lab)

Challenge Lab aims to create the framework for students to engage and dialogue with multiple stakeholders to tackle issues for a more sustainable society. The objective is for them to start their master thesis working on projects with a challenge-based approach on sustainable problems.

The course is run as a set of collaborating MSc thesis projects open for students of all disciplines at Chalmers. There is a dedicated space (the C-Lab) to promote dialogue and interchange of knowledge with stakeholders from industry, academia and the public sector.

The course aims for going further the traditional master thesis. Rather than just designing solutions they intend to implement it, making the students agents of change to society.

The learning outcomes of the course are related to sustainability (frameworks, paradigm shifts identification), leadership, dialogue, system transitions and design thinking, but also specialized knowledge within their own discipline, written and oral communication skills, etc.

The course first has a phase of problem formulation, where students have classes on research, leadership, Design Thinking and entrepreneurship among others, to support the process of defining the challenge to be solving. On the second phase, they work on conception-design and implementation of the solution, either individually or in pairs.

	UWA Global Challenges	Purdue EPICS	DTU Green Challenge	Chalmers C-Labs
Student year	Year 1	Year 1-4	Year 3-5	Master thesis
Learning outcomes (targeted)	Many, see taught topics below	Design-build-test Teamwork Communication Project planning Leadership Customer-awareness Ethics, economic, & legal issues	Communication, Environmental assessment, Visioning	Sustainability Systems thinking Leadership Design thinking
Taught topics	Project planning Waste Social impact Design Environment & sustainability Diversity, ethics and justice	Design Ethics Empathy Interviewing & observing methods Presentation Leadership Prototyping	Innovation pitch presentation	Backcasting Dialogue tools Design thinking Self-leadership Entrepreneurship
Typical project	Briquette press	Shelters for natural disaster areas	Improved efficiency of wind turbines	Biodiesel introduction analysis
Magnitude	10 ECTS	5-10 ECTS	5-30 ECTS	37.5 ECTS
Perspective	Global	Local – global	Local – global	Local
Focus	Social – environmental	Social	Environmental – social	Environmental – within the frame of a theme
Teacher team	Small	Large & including admin staff	Project-dependent	Moderate, multi-departmental + specialist supervisors related to subject areas
Cost/student	Moderate	Moderate-high	Low	High
Students/year (estimated)	45	400	250	20
Unique advantage	**Sets the scene for the entire program**	**Outreaching and inclusive. Large-scale**	**Flexible and inclusive**	**May lead to the deepest competence & implementation of results**

Table 18. Comparison of challenge-based learning experiences (Malmqvist et al., 2015)

As described by Malmqvist et al. (2015) the evaluation of the Challenge Lab (C-Lab) experience at Chalmers University of Technology, it was carried out by interviewing the students (the 12 students that participated in 2014). Among the positive aspects, students highlighted the interaction with stakeholders, the C-Lab space, working with people from different backgrounds (network), self-leadership, and the chance to decide the challenge themselves rather than working on an assigned task.

On the other hand, students struggled with the process (not clear when and how should they have contributed), not deepened enough on their specific area of knowledge, and were overwhelmed by the number of new tools and concepts.

The classes related to sustainability and towards learning the methods for challenge-driven projects were demanding. Although they were needed as students had very diverse background and as a conclusion it was clear that a compulsory preparatory course for the C-Lab was needed.

From the professors' side, it was concluded that scalability for this type of courses is an issue, as if the number of students would be many more, the methodology would be difficult to hold on to.

Having these open-ended problems, shifting the focus from a technical problem to a societal problem, in a more dynamic process (compared to design-build-test projects) and requiring multidisciplinary knowledge poses challenges both for faculty and students. Faculty in many cases will be less able to provide subject-related feedback and this for students may result in a felling of lack of support and feel more insecure.

Challenge-based learning raises the level of ambition of engineering education, going beyond the technical arena into the socio-technical domain. It also trains skills needed like multidisciplinary teamwork, decision-making, communication and leadership.

Another good example of the implementation of this approach could be Design Factory at Aalto University, consisting of an innovative experimental ecosystem for higher education with interdisciplinary principles and new teaching methodologies that "has been successful in and at the forefront in educating the students to be change-makers" (Munigala et al., 2018).

Challenge-based learning covers more competences related to innovation than Project-based learning, like multidisciplinarity and understanding solutions from a broader perspective than from a purely technical/technological approach. Although mixing engineering and business students has been done for challenge-based learning, what is not so common is also including design students in the mix. This brings interesting perspectives on competences like creativity and user awareness.

In conclusion, engineering education is evolving to better adapt to society's needs, where the fast changing and more uncertain context, the evolution of technology, the complexity and enormousness of the challenges we are now facing and will face in the near future like climate change, create a high level of uncertainty and puts great challenges for future engineers.

Dealing with uncertainty is an important aspect of the innovation process and a relevant innovation competence to be developed by future professionals, in order to be able to tackle the challenges we face (and will face) as a society. To deal with uncertainty, one of the possible strategies to develop is using and teaching Design Thinking, a methodology to approach innovation originated in the design discipline now being adopted in the management field, and further discussed in the following pages as a user centered innovation approach, compared to the "traditional" New Product Development approach.

1.8. Product Development Process and Design Thinking: Two approaches to innovation

Successful Product Development (PD) is critical to industrial performance (Unger & Eppinger, 2009). It could be added that this is valid not only to industrial performance but to companies' success, and even more, companies' survival. Rapid and innovative PD can provide critical competitive advantages to firms (Jachimowicz and Umali, 2000; Ulrich and Eppinger, 2008). This is especially valid when talking about startups, when resources are limited and time-to-market is critical, to generate revenue and sustain company viability.

For all the aforementioned, training future graduates in Product Development Process (PDP) is fundamental to guarantee a smooth integration in the industry world and to contribute to companies' success.

As in all innovation processes, there are uncertainties that imply risks. There are several PDPs, that are not uniform but in general they take similar actions to manage risks in development (Unger & Eppinger, 2009). Literature and industry standard processes describe a series of steps, phases or stages in the PDP with the purpose of generating a structure for managing the uncertainties and risks that companies face. As described by these authors, most companies follow some form of these steps: product planning, project planning, concept creation, system-level design, detailed design, testing/prototyping, and release. This is due to that by splitting the process into smaller actions is a way to manage and control risks.

Risk and uncertainty management is a key concern in Product Development, as it is defined as "exposure to danger or loss" is prevalent in all development projects and especially high in innovation projects. Multiple forms of development failure can be the result of these risks: slow or late PD may miss a market opportunity and increase development costs; a technically challenging product may be impossible to develop, may not have the expected features or don't have enough quality; and a product with incorrect specifications may not cover customer needs, thus completely miss a market niche (Awny, 2006).

As described by (Unger & Eppinger, 2009), a successful PDP should help to manage and/or mitigate the four major type of risks summarized in Table 19.

Type of risk	Description
Technical risk	uncertainty regarding whether a new product is technologically feasible and whether it will perform as expected, given clear and valid product specifications.
Market risk	uncertainty regarding whether a new product accurately addresses changing customer needs and whether the product is well positioned relative to competition. Unlike the technical difficulty of building 'to a specification', market risk concerns whether an achievable specification brings the wrong product to market.
Schedule risk	uncertainty regarding whether a new product can be developed in the time available.
Financial risk	uncertainty regarding whether a new product can be developed on budget and whether the project will pay back the investment

Table 19. Four major types of risk in PD (Unger & Eppinger, 2009)

This research focuses on Technical and Market risk, as those are the aspects that are better addressed in the courses analyzed within the scope of this investigation.

The traditional staged process described in Figure 14 (Cooper, 2001; Smith and Reinertsen, 1992; Ulrich and Eppinger, 2008), also called waterfall, stage gate, phase gate, checkpoint or life cycle among others, has been dominant in industry for more than 30 years (Unger & Eppinger, 2009).

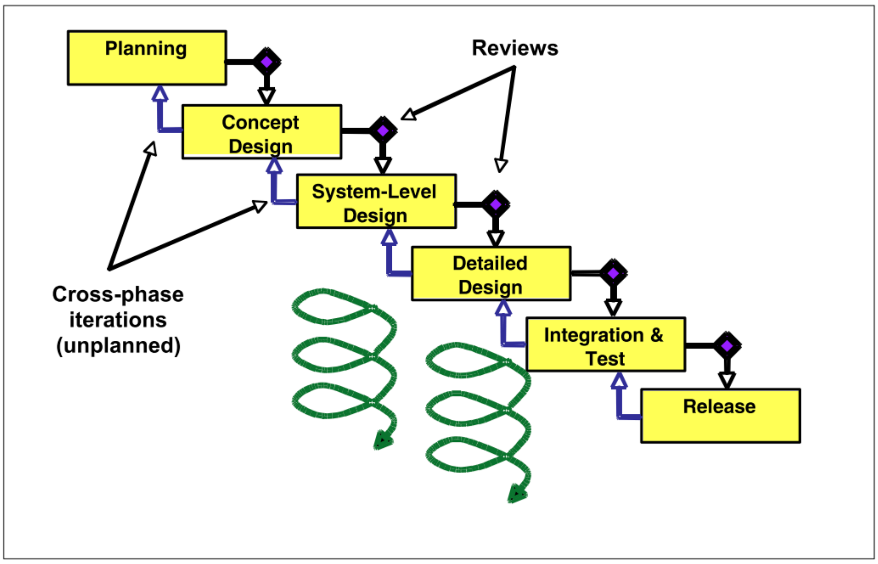


Figure 14. Traditional staged PDP (Unger & Eppinger, 2009)

This staged process, contemplates a review at the end of each phase to evaluate whether the previous phase was successful and decide whether to continue to the next or not. If not, iterations within that phase are performed until it can effectively pass the review, or the project may be canceled. Major unplanned cross-phase iterations are generally avoided whenever possible, as they are difficult and costly. Most iterations happen within phases. This structure in the product development process help sharpen product definition and specifications. These narrow iterations and reviews help freezing specifications early, thus reducing technical risk. Stable and rigid product specifications help to avoid errors. Having stable product definitions and using well known technologies is when staged process perform well (i.e. when doing upgrades o improvements to existing products). Finding errors in early stages of a project is one of the advantages of these staged processes, when the cost of changes is low (McConnel, 1996).

On the other hand, inflexibility is the biggest disadvantage of narrow iterations limited within phases. As they don't cross phase boundaries, iterations can't incorporate learnings and feedback from later stages. In many cases, it is difficult or sometimes impossible to completely specify requirements and specifications at the beginning of a project. This is especially hard in dynamic markets and in innovation projects, when the level of uncertainty is high. If early specifications are proven wrong by subsequent prototyping or market research, project failure may result potentially generating great losses. This cascade process doesn't manage midstream changes well and can be ill-suited for projects where requirements are not well defined in the beginning.

This process assumes some level of certainty at the beginning on what market or customer need is being addressed, and some level of specifications that the product must meet. In conclusion, the staged process is well suited for mitigating the technical risk but might be not enough for mitigating the market risk.

Market risk poses a higher level of uncertainty in any project. Especially when speaking about innovation, when not only the uncertainty is on whether the market will accept the product, but maybe the technology being developed is not validated (technical risk) and even the business model might be not defined. The complexity and the speed of changes in the world we are living, both social, economic and technological increases the uncertainty and the risk of developing new products.

Design Thinking arises in the past decade as an innovation approach widely recognized for effectively dealing with the high levels of uncertainty in early stages of the product development process. It is defined by Tim Brown (2008) as "a human-centered approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success". This innovation approach emphasizes people behaviors observation for detecting needs, multidisciplinary teamwork, quick and early visualization and prototyping of concepts to test them iteratively during the process. Design Thinking is for innovation early stages (Carr et al., 2010) and does not replace professional design or engineering (Charosky et al., 2018). It complements and reinforces the initial phases of innovation, and it is useful to reduce the market risk. Through an intensive user research process, it helps to detect real needs to be addressed, and through quick and dirty (inexpensive) prototyping, help to validate concepts with the market. This helps to refine and narrow the specifications, thus reducing the uncertainty before starting the "traditional" stage gate product development process. As observed in Figure 15, in the Design Thinking process it is highlighted the iterations between the different phases. New knowledge and feedback are gained as the project progress, it is encouraged to incorporate these learnings to refine the solution and validate it, through new interactions (testing) with users and stakeholders. This process of market validation reduces the market risk.

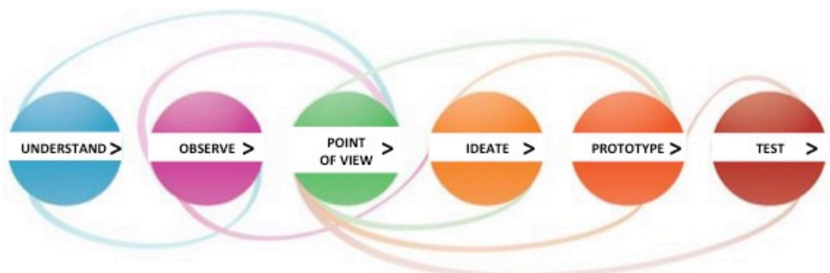


Figure 15. Design Thinking phases, Ratcliffe (2009)

In order to come up with innovative solutions to meet the market needs, a product development team needs to be skilled in exploration. Exploration is fundamental for innovation and refers to the innovative behavior involved in risk-taking and experimenting with unfamiliar alternatives. This search for new ideas, markets, or relations inevitably faces uncertainty; it has less certain outcomes than the further development of existing ones. At the outset of and exploration project, in many cases there is no clear predefined target, nor a known route to achieve it - certainly no requirements nor specifications, while classical product development projects often start from requirements or even directly from specifications. Therefore, exploration activities need to be supported by an appropriate methodology that is able to deal with the uncertainty, support the creation of the information required, and flexibly modify the direction of the project as new information becomes available.

Design Thinking is an iterative and human-centered approach to innovation, originating from the design disciplines and drawing from the tools and methods utilized traditionally by designers. This methodology has been credited for its specific support for reflective reframing, integrative thinking, abductive reasoning, and dealing with uncertainty and ambiguity - all conditions for successful exploration (Hassi and Laakso, 2011; Dunne and Martin, 2006; Dym, et al. 2005).

1.9. NPD – New product development

People are commonly trained in analytical thinking, especially engineers. They break down problems into smaller parts in order to solve them, creating from then attempts to design future solutions based on data from the past (Efeoglu et al., 2013).

In the classical product development process, we can define a project as a connected sequence of unique and complex activities, with a single goal or purpose that should be completed in a specific time and with a given budget, according to a specification (Ulrich & Eppinger, 2008).

As mentioned above, the process described by Ulrich and Eppinger (2008) can be considered the "industry standard" and is the one taken as a reference for this research.

This type of process assumes a certain level of knowledge upfront and during the project development. It consists generally of a sequence of steps or activities, usually six or more, that the designer or company employs to conceive, design and manufacture a product (Figure 16). The phases, the key activities and outputs of each phase are described in detail in Table 20. The concept development is the key activity that demands more coordination among the other functions. It includes the activities depicted in the lower part of Figure 17. In practice these activities may overlap in time and iteration is often necessary.

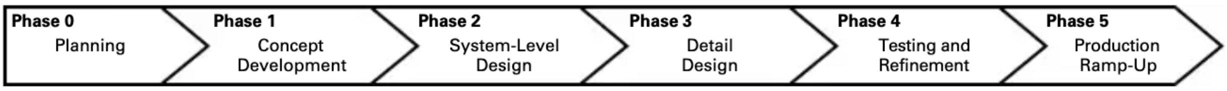


Figure 16. Phases of product design Ulrich-Eppinger (2008)

Phase	Key activities	Outputs
0. Planning	. Opportunity identification based on corporate strategy . Assessment of technology developments . Market objectives definition	Project mission statement: -Target market for the product -Business goals - Key assumptions -Constraints
1.Concept development	. Identification of target market needs	Concepts description: -Form -Function -Features of a product

	. Alternative product concepts generation and evaluation . One or more concepts selection for further development and testing.	-Set of specifications -Analysis of competitive products -Economic justification of the project
2. System-level design	. Definition of the product architecture . Decomposition of the product into subsystems and components. Preliminary design of key components . Initial plans for the production system and final assembly	-Geometric layout of the product -Functional specification of each product's subsystems, -Preliminary process flow diagram for the final assembly process
3.Detail design	. Complete specification of the geometry . Materials and tolerances of all of the unique parts in the product . Identification of all of the standard parts to be purchased from suppliers . Process plan . Tooling design for each part	Control documentation for the product: -Drawings or computer files including each part geometry and its production tooling -Specifications of the purchased parts -Process plans for the fabrication and assembly of the product. -Materials selection -Production cost -Robust performance
4.Testing and refinement	. Construction and evaluation of multiple preproduction versions of the product: Alpha (Usually built with production-intent parts (same geometry and material properties as intended for the production version) and Beta prototypes (usually built with parts supplied by the intended production processes).	-Alpha prototypes that are tested to determine whether the product will work as designed and whether the product satisfies the key customer needs. -Beta prototypes are extensively evaluated internally and are also typically tested by customers in their own use environment. Its aim is to validate performance and reliability in order to identify potential engineering changes for the final product.
5. Production ramp-up	. Product is made using the intended production system	-Workforce training and to work out any remaining

		problems in the production processes and transition gradually to ongoing production. -Postlaunch project review may happen, to assess both commercial and technical improvements for future projects.

Table 20. Phases, key activities and outputs of Product Development Process (Ulrich & Eppinger, 2008)

Concept Development

Ulrich & Eppinger call the Concept Development phase "The Front-End Process", because this phase demands more coordination among functions and generally contains many interrelated activities as shown in Figure 17. It rarely is sequential and many of them proceed in parallel and overlapping in time, and iteration is often necessary. The uncertainty level is high within this phase, represented by the dashed arrows shown in the figure. As new information becomes available, can cause the project team to go back to repeat an earlier activity before moving to the next phase. This is known and development iterations.

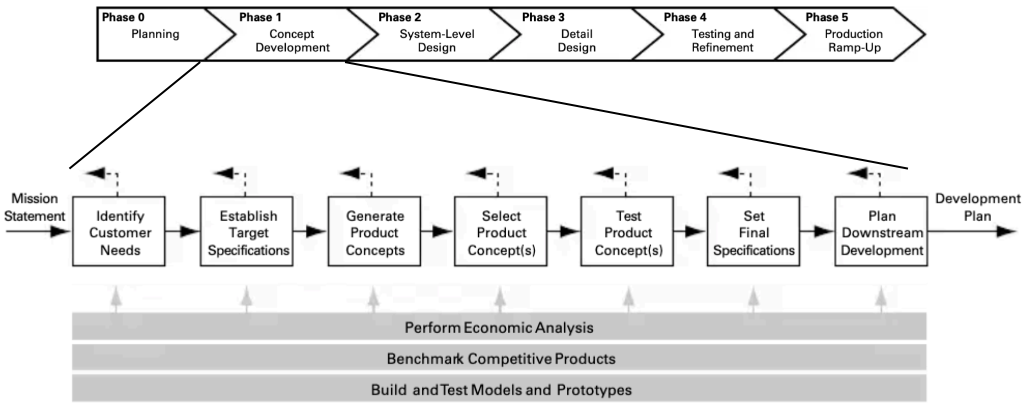


Figure 17. Activities within the concept development phase (Adapted from Ulrich-Eppinger, 2008)

The specific activities, goals and outputs of the Concept Development phase are described in Table 21.

Activities	Goals	Outputs
• Identifying customer needs	Understand customers' needs and effectively communicate them to the development team.	Customer need statements, organized in a hierarchical (with weightings) list.
• Establishing target specifications:	Provide a precise description of what a product has to do. To translate customer needs into technical terms.	List of target specifications with a metric, and marginal and ideal values for it.

•Concept generation	Thoroughly explore the space of product concepts that may address the customer needs, including: -mix of external search -creative problem solving -systematic exploration of solution fragments	A set of (usually) 10 to 20 concepts, typically represented by a concept sketch and brief description.
•Concept selection	Several product concepts are analyzed and sequentially eliminated to identify the most promising concept(s). It normally requires many iterations and may trigger additional concept refinement or new concepts generation.	Selection (list) of concept(s) to be further developed.
•Concept testing	Concept(s) are tested to validate that customer needs are been met. Also, to assess market potential, and identify any deficiencies	Feedback report with testing results. If customer feedback is poor, previous activities might be repeated or project may be terminated.
• Setting final specifications	Target specifications set earlier in the process are re-visited after concept selection and testing.	Team commitment to specific values of the metrics reflecting the constraints inherent in the product concept. Limitations identified through technical modeling are defined and trade-offs between cost and performance are made.
•Project planning	Creation of a detailed development schedule, a strategy to minimize development time, and identification of the resources required to complete the project.	Specifications and requirements captured in a “contract book”, that serves to document the agreement between project team and senior management. It contains: . mission statement . customer needs . selected concept details . product specifications . product economic analysis . development schedule . project staffing . budget

Table 21. Activities, goals and outputs of Concept Development phase (Ulrich & Eppinger, 2008)

Also, as observed in Figure 17, there are three tasks carried out in parallel to the aforementioned activities along the Concept Development phase:

Economic analysis: used to justify the continuation of the project and to make trade-offs during the product development process (i.e., development costs vs. manufacturing costs). It is normally done even before the project begins and is updated as more information becomes available.

Benchmarking of competitive products: Understanding competitive landscape is fundamental to successfully position the new product. Also, it is an excellent source of ideas both for the product and production process design. This activity may support many of the activities performed during the concept development phase.

Modeling and prototyping: Every stage of concept development may involve several forms of models and/or prototypes. These may be proof-of-concept (to demonstrate feasibility), form-only (to evaluate ergonomics and style), spread-sheet models (document technical trade-offs) and experimental test models (to set design parameters for performance robustness), among others.

To link the Product Development Process described above with engineering education, is where CDIO comes into place with its Conceive – Design – Implement – Operate framework. "Conceive" is the first of the four phases in the product lifetime defined by the CDIO paradigm. CDIO Standards clearly state that the Conceive stage includes defining customer needs, considering technology, enterprise strategy, and regulations and developing conceptual, technical, and business plans. On the other hand, CDIO Syllabus 2.0 refers to the conception phase taking into account the customer and societal needs in points 4.3.1 (Understanding Needs and Setting Goals), 4.4.2 (The Design Process Phasing and Approaches), 4.4.5 (Multidisciplinary Design) and 4.7.8 (Innovation – the Conception, Design and Introduction of New Goods and Services).

Nevertheless, most points of the Syllabus section 4 and most engineering curricula put more emphasis in "Design" and subsequent phases and students' projects often start from requirements or even directly from specifications, even if an external stakeholder stated them. As described by Hassi et al. (2016), this is because usually the interlocutors in the companies or institutions that specify the product are also normally engineers. On the other hand, this allows that projects can reach a high technical complexity and that students would learn how to deal with it.

Product designers and designers from all disciplines devote more time and put more emphasis in understanding user needs. It is often assumed that engineers need that another agent (product design, marketing, management...) states the requirements. This situation, although normally assumed by engineering students, it may limit the capability of graduated engineers on participating in the concept creation and decision making at higher level of the Product Development Process.

As mentioned before, in recent years, new terms like Co-Creation or Design-Thinking (DT) have arisen as ways of dealing with the uncertainty involved in the conception phase. A few references can be found in the CDIO knowledge library about this approach, most of them from Singapore Polytechnic (Fai, 2011; Yang and Cheah, 2014; Ping et al., 2011) which has included specific courses in their curricula. There are also references in Taajamaa et al. (2014).

1.10. Design Thinking

What is Design Thinking?

The foundations of Design Thinking (DT) were laid around the mid 1970's and late 1980's within design research (Hassi and Laakso, 2011), focusing on understanding "the way designers think as they work" and drawing from the practice of professional designers, for example architects (Johansson and Woodilla, 2009). While design research keeps building on its broad research history on Design Thinking, the concept has gained increasing interest in other fields, such as engineering (Dym et al, 2005) and management (Kolko 2015; Dunne and Martin, 2006), where it is regarded as a methodology for innovation, problem solving, and value creation (Brown, 2009; Johansson and Woodilla, 2009).

Following Brown's (2009) description, Design Thinking begins with skills designers have used and developed over many decades, while aiming to match human needs with available technical resources, and within the practical constraints of business. The tools from the "designers toolkit" are put into the hands of people who are not professional designers, and they are being applied to a vast range of problems (Brown, 2009). Design Thinking is essentially a human-centered innovation process that emphasizes observation, collaboration, fast learning, visualization of ideas, rapid concept prototyping and concurrent business analysis. It is not a substitute for professional design, but rather a methodology for innovation in the early stages of the innovation funnel. (Lockwood, 2010).

Some of the promoters of Design Thinking have been Apple and SAP. They both collaborated with IDEO, the innovation consultancy founded by David Kelly, Bill Moggridge and Mike Nuttall. David Kelley together with Tim Brown (current CEO of IDEO) are among the creators and formalizers of Design Thinking, and the ones who brought it out from university and design context, to business practice and other disciplines.

Hasso Plattner, the co-founder of SAP invested in the university campus of Stanford, creating the Hasso Plattner Institute of Design (the "d.school"), which is probably the most renowned institution on Design Thinking (education and research).

Design Thinking is being adopted by different organizations as an innovation approach because it is not limited to designers and is being carried out as a managerial task by all sorts of profiles (Shamiyeh, 2010). In fact, it is becoming part of the business strategy of companies (Badke-Schaub et al., 2010).

Despite the lack of a consensual definition for Design Thinking, the definitions seem to have some key tenets in common, such as, human-centricity, rough prototyping, iterative knowledge creation, and reflection (Hassi and Laakso, 2011; Lockwood, 2010). Perhaps the most prominently emphasized issues in Design Thinking is its inherent and thorough human- centered approach (Brown, 2008; Porcini, 2009). All depictions of Design Thinking are extremely consistent in emphasizing developing empathy towards the user, to have a deep understanding of their motivations, needs, and fears (Lockwood, 2009; Clark and Smith, 2008; Dunne and Martin, 2006).

The Design Thinking process can be viewed as an exploration of a problem space and solution space, i.e. within the scope of the challenge, identifying and evaluating alternative problems to be solved and different solutions to address the chosen problem. In terms of cognitive processes, it is a combination of divergent and convergent thinking, where a set of choices is first created, and only then are choices made between the alternative options (Brown, 2009). Ratcliffe (2009) describes Design Thinking as a six phase, iterative process involving back-and-forth movements between the different phases (Figure15).

Newell et al. (1967) described the problem space, asking for comprehensive understanding problems, assuming that solutions can be obtained within the problems' inner structure. Newell proposes a combined exploration of problem and solution space in parallel (1979) and Cross (2001) proposes a separation of problem and solution spaces. The "co-evolution of problem and solutions" proposed by Dorst and Cross (2001) seems to better describe reality, as solutions evolve, new understanding of the problem occurs (i.e. when testing a prototype with users, we learn both about the solution itself and also we learn more about users' needs).

Bringing perspectives from outside the problem can lead to more innovative solutions. Also, as the problem understanding evolves, naturally we start thinking on solutions.

Nevertheless, it is fundamental to clearly understand the problem before deep diving and put developing efforts into solutions, to avoid wasting time and resources exploring solutions that don't fundamentally solve the problem.

A divergent and convergent questioning process

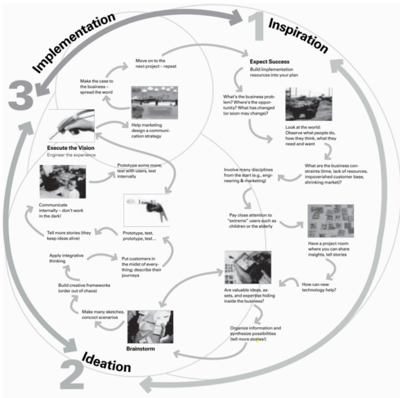
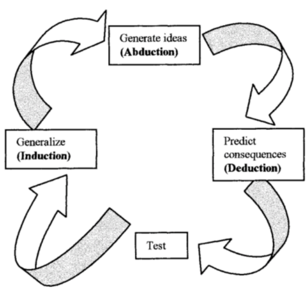
Aristotle suggested that "the kinds of questions we ask are as many as the kinds of things which we know" (Barnes (transl.), 1994). Thus, it could be said that knowledge is based on the quality of the questions asked and the answers provided.

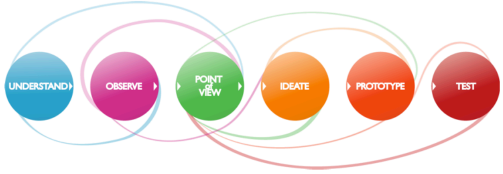
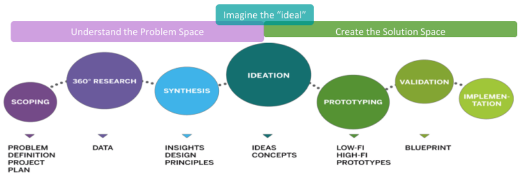
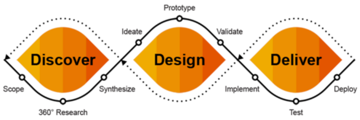
Dym et al. (2005) describe the diverging and converging process associated with Design Thinking. They say that it is commonly understood that for a given question, a specific answer or a specific set of possible answers exist. These types of questions are typical of convergent thinking. The person asking the question seeks to "converge" and discover "facts". Thus, the answers to converging questions are expected to be demonstrable, to be hold truth. Deep reasoning questions are that type of questions.

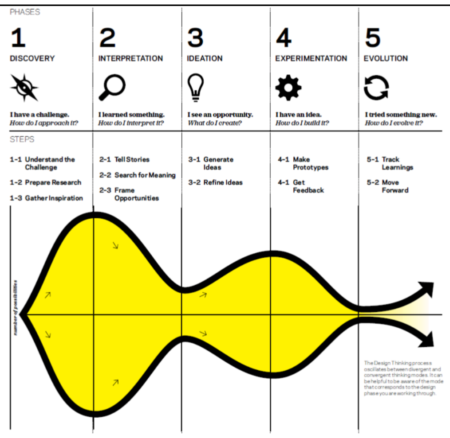
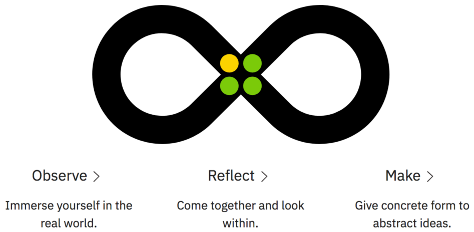
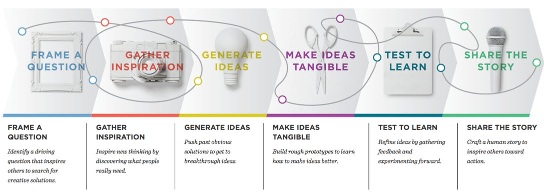
In design situations, questions asked normally are under an opposed principle: for any given question, there exist several different known answers, whether they are true or not, as well as many not known possible answers. The person questioning looks for disclosing the alternative known answers and to create the unknown conceivable ones.

These questions are characteristic in divergent thinking, where inquirer intents to diverge from facts to the opportunities that can be built from them. These types of questions were described as generative design questions by Eris (2004). The inquirer is not necessarily worried about the truthfulness of the answers or the possibility of confirming potential answers when asking a generative design question. The fundamental difference is that convergent questions work in the knowledge space and divergent questions work in the concept space. Thus, as stated by Dym et al. (2005) "Design Thinking is a series of continuous transformations from the concept domain to the knowledge domain". Thus, in Design Thinking are included both asking deep reasoning convergent questions and divergent generative design questions, which create the concepts where the convergent component can operate.

There are many different approaches and processes for Design Thinking from different authors and institutions. Even there are different "flavors", they all share a common philosophy of exploration, human-centricity and iteration as observed in Table 22, adapted from Efeoglu et al. (2013).

Author/s - Name	**Process**	**Comments**
Tim Brown's three step Design Thinking approach (2009)	 Figure 1. Tim Brown's three-step Design Thinking approach (Brown, 2009)	Circular three core steps: Inspiration, ideation & implementation. Inspiration: related to both problem & market opportunities. Ideation: generation, development and test of ideas Implementation: focus on readiness for marketability of the product/service/solution. Innovation refinement through iteration through the phases. Non-linear, process can go from any phase to any other.
Dune and Martin's Design Thinking Cycle (2006)	 Figure 2. The cycle of Design Thinking (Dunne and Martin, 2006)	Design Thinking as a process to solve "wicked problems", applied to projects with expected deadline. 4 Phases: Inductive, deductive, abductive and test. Induction and deduction comparable to divergence and convergence. Abductive thinking is what can generate really new ideas. Testing of ideas in practice.

The Stanford D.School Design Thinking process (Ratcliffe, 2009)		Sequential approach comprised of 6 iterative (directly or indirectly related) phases, divided into 2 clear spaces: the problem space and the solution space. Probably the approach the better represents the nature of the combination of linearity (moving forward) as well as the iterativity (back and forth) of the process.
Imagine, Create & Innovate – Design Thinking with SAP (Serie, 2012)		Very similar to the Stanford D.School approach (Hasso Plattner supported the creation of that school and Design Thinking process). Main differences are the names used to describe phases and an additional phase focusing on implementation. Aim is to create products/solutions that can actually be launched to the market.
Design Thinking with SAP, The process to innovate (2018)	 	The SAP process today shows the diverging and converging essence of the Design Thinking process and is comprised of three phases: Discover, Design and Deliver, aiming to get to the "root of the problem building optimism both for problem finding and real problem solving solutions. Also, shows the iterative loops through the color code within each phase and the cycling arrows.

Design Thinking Toolkit for Educators (IDEO, 2021)		The approach was developed by IDEO and Riverdale School in New York. Similar to the d.School approach, but with only 5 phases: Discovery and Interpretation in the problem space; and Ideation, Experimentation and Evolution in the solution space. It emphasizes visually the relevance of the diverging and converging thinking of the process
IBM Enterprise Design Thinking, The Framework (2018)		The Framework is composed of "The Loop" which represents the continuous cycle of the three phases: Observe, Reflect and Make. Focus is on user outcomes, staying essential by treating everything as a prototype and moving fast by empowering multidisciplinary teams with a bias towards action (make). It is described as an ongoing conversation of problems and solutions.
IDEO U, A process for creative problem solving (2018)		The framework from IDEO U, the online school from IDEO "where anyone can unlock their creative potential through design thinking and collaboration" stands for a 6 phases Design Thinking process. It starts with Frame the Question and Gather inspiration in the problem space. Then generate ideas, make ideas tangible (prototype) and test to learn in the solution

		space. Then, it has a final phase of Share the story, aiming to “inspire others towards action”

Table 22. Comparison of different Design Thinking approaches (adapted from Efeoglu et al., 2013)

All design thinking approaches/methods comprise divergent and convergent thinking in all phases and also, they all have two well-differentiated spaces: the problem space and the solution space. Even though some are circular, and others are linear, in all cases the iterativity of the process is present.

Design thinking works best for “wicked problems”: not well defined, with high complexity and not precise. Complexity of these problems cannot be tackled with traditional problem-solving approach, using only rational and analytical approaches (Bauer and Eagan, 2008).

Devoting in all approaches a significant amount of time (two or three phases of the process) to understanding the problem highlights the importance of the diagnosis. It is probably the most important part of the process.

As stated by Efeoglu et al. (2013), “the solution can only be as good as the problem is understood”. Like in medicine, a lot of time is invested in exploring patient’s symptoms before diagnosis. Once it’s clear (and curable), healing can be simple.

The human centricity is a fundamental aspect of the Design Thinking process, which does not differ from von Hippel (1998, 2005) of user-driven innovation.

Characteristics (based on Efeoglu et al. (2013):

- Problem & solution space clearly defined
- Divergence and convergence of the process
- Iterativity
- Key importance of problem understanding
- Collaboration and teamwork
- Ideation and experimentation
- Prototyping and early visualization of ideas

Description of the Design Thinking process

To go in-depth in the description of the Design Thinking process, the d.School from Stanford (Ratcliffe, 2009) was selected, as it could be said it is the foundational institution for Design Thinking and has the most detailed and explicit phase name tags. The phases and its diverging and converging characteristics are shown in Figure 18.

The process begins with understand, forming a general understanding of the situation and challenge at hand and formulating an initial problem statement. During this phase, a product development team speaks with experts, conducts background research on the topic, and develops their understanding of the challenge to a level that allows them to identify ways to address the design challenge. While developing solutions to design problems is a well-recognized skill of designers, the ability to think up new ways of looking at the problem in the first place is key as well (Dew, 2007). This ability is referred as reflective reframing of the problem or situation. Design Thinking encourages questioning the way a problem is represented (Boland and Collopy, 2004), looking beyond the immediate boundaries of the problem to ensure the right question is being addressed, and identifying, framing, and reframing the problem to be solved are seen as equally important as solving the problem or finding an appropriate solution (Beckman and Barry, 2007).

One of the outcomes of the understand phase is the identification of key stakeholders and potential users. This gives the team an entry-point to the second phase, observe, where the objective is to learn how people behave and interact in the context of the challenge. This phase is also called needfinding, as the aim is to develop a deep understanding about the needs and problems of the user. At this phase the ethnographic research methods come to play, and where empathy for the user is developed. In addition to observation, the methods deployed here, include for example interviews, shadowing, “living the life of the user” (i.e., immersing into the experience the user goes through).

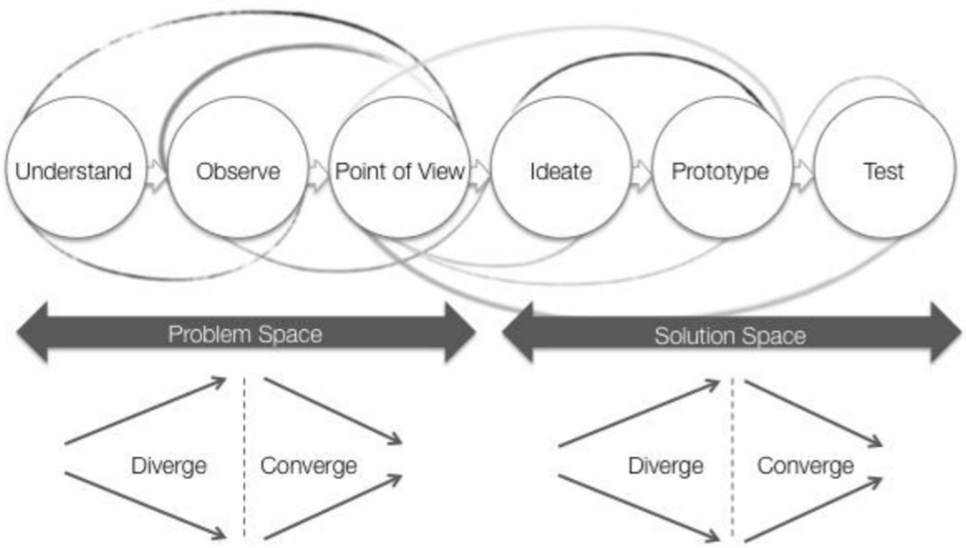


Figure 18. Steps in a Design Thinking process (adapted from Ratcliffe, 2009)

When defining a point of view, the team analyses and draws conclusions from the findings of the previous phases: are there patterns, surprises, meaningful details that could give direction to the following phases. This phase is essentially about reflecting on the information created and collected so far, and interpreting that into a new, better focused and defined problem statement. Here, an often-used model for the reformulation of the problem starts with the question “How might we...?” which is followed by the description of the user, his/her need and a specific insight that gives clues for a possible solution. This point of view statement becomes the starting point for idea development.

When developing ideas, quantity is encouraged (Brown, 2009). The challenge is to cover as much of the potential solution space as possible, and to do so the team must suspend judgments. Ideation itself is an iterative divergence and convergence, where idea generation is followed by their analysis and selection, and then a new ideation round is done to either increase variety amongst the existing idea, or to produce detail to the already existing ones. Selected idea(s) are then prototyped and tested.

Early, rough, and quick prototyping is a central part of the iterative and highly tangible approach favored by designers - and a cornerstone of Design Thinking. Early – “from day one” – and continuous prototyping is considered necessary and beneficial throughout the entire process (Brown, 2008; Fraser, 2007). Quick prototyping refers to creating many inexpensive and rough conceptual artifacts, to promote reflection and the generation of new ideas (Fai, 2011). Prototypes are, in fact, primarily seen as a tool for stimulating thinking and exploring ideas, not as representations of the products (Boland and Collopy, 2004). They are created to facilitate thinking and knowledge creation, to make concepts concrete, and to help the exploration of numerous possible solutions (Fraser, 2007, Lockwood, 2009). They are low-cost representations of the idea: sketches, cardboard models, or rough digital mock-ups, that are created with the purpose of receiving early feedback from the users with minimum investment of resources. The less is invested, the easier it is to modify the direction of the project if the received feedback so requires.

This is a key phase of the Design Thinking process and might be considered the most important part for some advocates of it. It is the moment where ideas are made tangible, taking the conversation to another level, going beyond the pure speculation to a concrete discussion about something "real", that already exists. These prototypes don't need to be physical objects. Can be digital or visual representations of the idea.

Testing the prototype with users shows what works, what doesn't. Reflection on the information gained from testing gives direction for the next iteration, i.e., how the idea and the prototype need to be modified. The process of challenging the original problem is not limited to the beginning of the process, but is ongoing, incorporating the findings already gained to re-phrase the problem.

As described by Efeouglu et al. (2013), Timeboxing is a very relevant topic for the Design Thinking process. Time framing a specific task is crucial. In traditional project management time is allocated to all tasks to generate a "project network path", but in Design Thinking context is a bit different. Time boxing refers to the current task in the phase, and the time allocation for that specific task (Thoring and Müller, 2011). The concept of time boxing is broadly accepted in agile project management (Oesterreich and Weiss, 2008). Based on experience, time awareness prevents or minimizes long-lasting discussions. The benefit of time addition is low, because the value added to results generated during that extra time is minor.

The complexity of the challenges that today's society is facing requires more than a methodology or a process to tackle them. The knowledge required to approach any societal challenge comes from different disciplines, and in the combination of these different knowledge and approaches can lay the value creation for creating relevant solutions with greater chances to succeed.

1.11. Comparing Design Thinking and NPD

If we look at the block diagram that describes the phases of design according to the Design Thinking approach (Figure 18) and compare them with those depicted in the diagram of the "Concept Development" phase (Figure 17, lower part), it may look like both are describing the same process. Apparently, both start with understanding (needfinding) the customer needs, both stablish target specifications (Point of View), both develop several product concepts (ideate) ant test them through prototypes, to finish with a single product concept defined through final specifications. Where is then the difference? When engineers start dealing with "Identify Customer Needs", they usually know that the product is a given device, e.g. a wheelchair, and the needs are defined around the use of this device and the alternative analysis is performed on variations of this device or their parts. The same alternative analysis in the Design Thinking approach is not even in a preliminary phase of the solution but in the different needs identification in a given, broad environment e.g. elder mobility.

The design process assumes a certain level of information upfront and during the project development. According to Loch, "Main reason for project failure is that organizations do not recognize the fundamental difference between project novelty and project risk. Novel projects pose unforeseeable uncertainty." (Loch et al., 2006). In today's projects, complexity is increasing and the risk of product failure in the market is extremely high. Companies have to deal with a high level of uncertainty in innovation projects. In many cases there is not enough information, and it is not possible to precisely describe and define neither the current state nor the expected outcome. Moreover, in innovation projects there could be (and usually is) that one problem has many possible and different outcomes.

Loch et al. (2006) identify three fundamental project risk management approaches in face of uncertainty: the planning approach, iterate and learn approach, and selectionist approach (Figure 19).

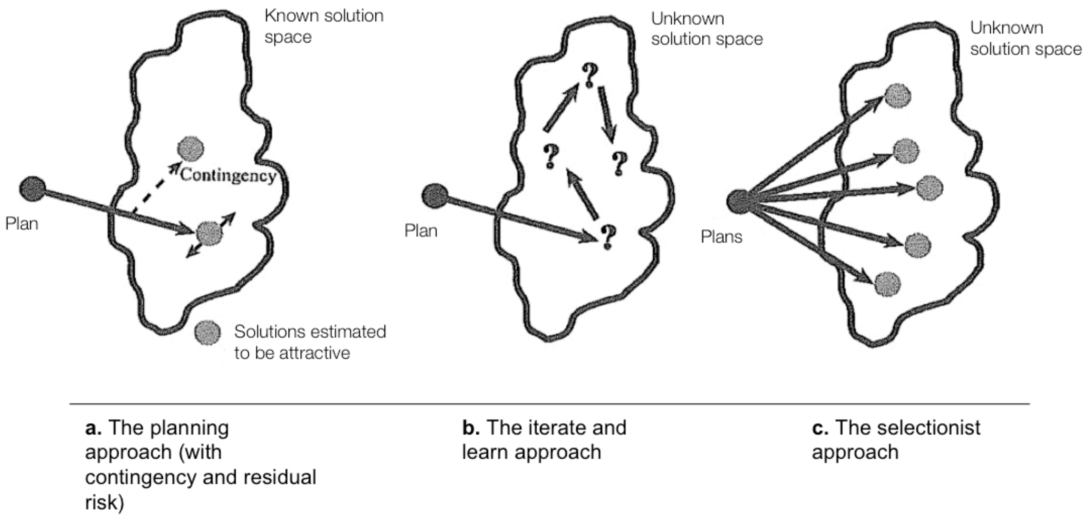


Figure 19. Three approaches to project management in face of uncertainty (Loch et al. 2006)

The planning approach (with contingency and residual risk) could be considered the most classical approach and is deployed when entering a known solution space. In this approach, the important problem solving occurs at the beginning of the project and then the emphasis shifts to executing the plan. There is a relatively high level of certainty and plenty of information at the outset. The outcome depends on the input at the beginning of the project, which proceeds with a pre-made plan with strong organizational pressure to support it.

The iterate and learn approach is well suited for projects in unknown solution space. It starts by planning and moving toward one outcome, which is the best that can be identified, with the information available upfront. The project team must remain prepared to repeatedly and fundamentally change both the outcome and the course of action as the project proceeds. This is due to the high level of uncertainty and lack of information available when starting the project. As new information becomes available, better-informed decisions can be made. This may force to iteratively modify the outcome.

The selectionist approach is characterized by pursuing multiple paths; independently of one another and picking the best one ex post characterize this approach. As the "iterate and learn approach", this approach is well suited for unknown solution space, where the level of uncertainty is high at the beginning. As the project moves forward, more information is generated allowing deciding which paths to follow and which ones to discard.

In a simplified analysis, the first and more systematic approach is the one usually employed in classical engineering design, and this allows using modeling and analytical tools to optimize both the design process and the design results. Systems of Systems approach (Keating & Katina., 2011) or Complex Systems Architecture (Crawley et al., 2015) provide focus and analytical tools to deal with very complex systems in a known environment. However, in uncertain environments, such as for example the creation of novel products, services or processes, the project outcome or the means to reach it are unknown at the outset of the project. Here, the iterate and learn, and the selectionist approach provide a more suitable support for the development process. Design Thinking is essentially aimed at creating information and knowledge. Hence, it bears strong resemblance to the iterate and learn approach, that relies on creative problem solving and reframing as the project proceeds.

Design Thinking has been progressively incorporated in the last years in some courses in engineering education as an approach to develop creativity and user-centred design and divergent thinking, integrating social and technical knowledge, collaborative, inquiry-drive, collaboration, critical thinking and communication (McKilligan et al., 2017, Charosky et al., 2018, Coleman et al., 2019, Lynch et al., 2019, Thiruvengadam et al., 2020).

Chapter 2 - Research framework: PDP and CBI

Once reviewed the literature to identify the innovation competences for engineering graduates and the different educational strategies to develop them, we aimed to analyze, 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 analyzed two courses developed at ICT engineering at Technical University of Catalonia (UPC): PDP course (Product Development Project) and the CBI course (Challenge Based Innovation).

In this chapter, the research framework used for developing this thesis investigation is explained. A detailed explanation of the two aforementioned project-based and challenge-based courses carried out by UPC Telecom engineering students: PDP (Product Development Project), the capstone project from the 4th year of the Telecom Engineering degree and CBI (Challenge Based Innovation), a new educational experience carried out by three higher education institutions: UPC (Telecom and Computer Science students), the business school ESADE and the Barcelona site of IED, Istituto Europeo di Design.

PDP (called Advanced Engineering Project) is a mandatory project-based course developed since 2012, within the CDIO (Conceive-Design-Implement-Operate) framework (Crawley et al., 2014) that follows the classical product development process described by Ulrich-Eppinger (2008) to solve a technical challenge posed by a company or institution.

Also, since 2014 students can opt to take CBI (as an alternative of PDP), a course with a challenge-based learning approach (Malmqvist et al., 2015) combined with Design Thinking methodology (Brown, 2008, 2009, Ratcliffe, 2009).

Challenge Based Innovation (CBI) is part of a IdeaSquare, a CERN program that hosts innovative educational projects (Hassi et al., 2016). Within IdeaSquare several CBI editions are carried out with different institutions. The most relevant are:

- CBI A3, with students from Design Factory Melbourne, inno.space Mannheim, New York City Design Factory, Porto Design Factory.
- CBI ER, with students from University of Bologna, University of Modena and Reggio Emilia and University of Ferrara, all of them in Italy.
- CBI Barcelona (CBI Mediterranan until 2017), with students from UPC Telecom (engineering), Istituto Europeo di Design (design) and ESADE Business School (management)

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 IdeaSquare at CERN, one of the nodes of the Aalto Design Factory Global Network (DFGN).

The author of this research and its thesis director participated in the conceptualization, design and implementation of the CBI course since 2014. Also, since 2009 the thesis director, Ramon Bragós is the Associate Dean for Academic Innovation at ETSETB-UPC and coordinator of project-based courses, including the Advanced Engineering Project (PDP Course) and Challenge Based Innovation (CBI Course). This allowed to have clearly differentiated groups of study to analyze and compare results in innovation competences development.

The description of both courses was published in the articles "Mixing Design, Management and Engineering Students in Challenge-Based Projects" (Hassi et al., 2016) in the Proceedings of the 12th International CDIO Conference, Turku University of Applied Sciences, Turku, Finland, June 12-16, 2016 and in "Challenge based education: an approach to innovation through multidisciplinary teams of students using Design Thinking" (Charosky et al., 2018) in the XIII Congress of Technologies Applied to Electronics Teaching (TAEE): proceedings: Universidad de La Laguna, Tenerife, Spain. The author of this thesis is co-author of the aforementioned articles.

2.1. PDP – Product Development Project

When designing the engineering degree curricula according to the EHEA directives, the Telecom Engineering School from UPC adopted the CDIO Standards (Crawley et al., 2011). As part of the implementation of the CDIO model, it included a project courses path which currently includes a project-based course in the second, third and fourth year of the bachelor (Bragós et al, 2012). The projects' complexity and degrees of freedom grow along the three iterations and also the team size increases.

PDP (Product Development Project) is the capstone project, called Advanced Engineering Project. It is located at the first term of the fourth year and has 12 ECTS which means 300 h of workload per person during 15 weeks in the semester. Most part of the time consist of autonomous work. Also, the students attend to weekly seminars of 2 hours, and have 6 supervised hours attendance to the lab per week.

As observed in Table 23, the topics of the short seminars (1-2 hours) consist in: Agile methodologies, innovation strategies, systems thinking, critical thinking, ethics, patents database search, IPR among others. They also attend longer seminars (several sessions) on advanced project management and on how to prepare a business plan.

Session	Seminar Track
1	Project management – PMBOK 1
2	Project management – PMBOK 2
3	Alternative project management. Agile methodologies.
4	Environmental, Economic and Social Sustainability.
5	Innovation strategies. Start-up opportunities at UPC.
6	Systems thinking and structured design
7	Critical thinking and Engineering Ethics
8	Patents database search and IPR strategy
9	Tools for innovation and entrepreneurship. Business Model Canvas, Lean Startup
10	Tools for innovation and entrepreneurship. Business Model Canvas, Lean Startup
11	Business Model Tutoring.
12	Business Model Tutoring.
13	Business Model Presentation.

Table 23. PDP List of seminars

Teams of 9-12 students face a complex industry challenge by splitting in sub-teams, designing and implementing the different parts of the project and finally integrating and testing the product, process or service, including the definition of a business model.

As required by course design, the product or system to be designed and built must have enough complexity to be split in 3-4 subsystems. Then, the team (9-12 students) is divided in sub-teams of 2-3 students (Figure 20) to design, build and test their assigned subsystems to later on integrate it with the others in order to complete the whole system. This approach intensifies sub-team and full-system level coordination, promoting several CDIO skills covered in the 3.1 and 4 of the syllabus.

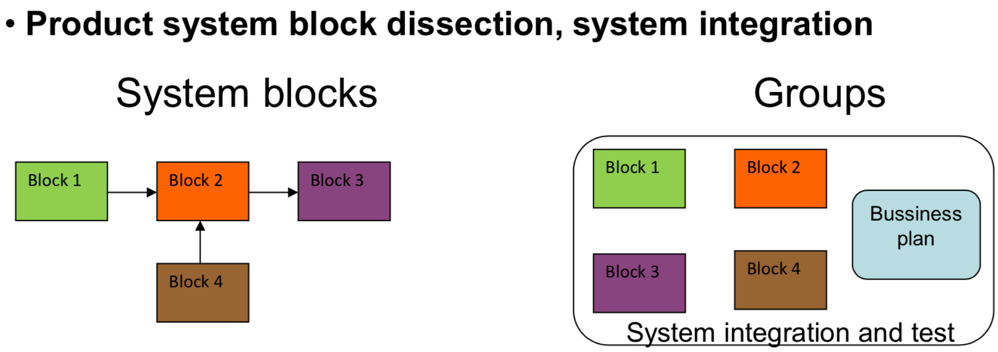


Figure 20. Product system blocks and system integration by student teams in PDP

The teams' structure consists of a project leader of the whole project (system) and a sub-project responsible for each sub-system block. The role of faculty is to act as supervisors and consultants, letting the students to act with a high degree of autonomy.

The teams usually have a mixed composition of students from the different minors of the Telecom Engineering degree (Electronics, Networks, Audiovisual Systems and Communication Systems). The appointed project leader is chosen by the team members. He does not receive any specific training and participates in the final evaluation.

This subject has also evolved along the iterations since it was first implemented in 2012. Currently, eight to ten different challenges are offered every semester. Seven to eight out of ten are proposed by companies or external institutions (hospitals, NGOs, ...) and two or three are proposed by research groups from the UPC which have a strategic character for the School (i.e., nanosatellites, 5G, ...).

The projects follow a traditional product development process (Ulrich & Eppinger, 2008) structure. They start with requirements and sometimes even specifications, to solve a technical need identified by the stakeholders. The teams build a Project Charter document, adapted from the LIPS model (Svensson & Krysander, 2011) and a Project Management Plan, following a simplified version of the PMBOK (2013) standard, and get them approved by the faculty members and the external advisors. The teams have weekly meetings and three review meetings with faculty as observed in Figure 21 and Table 24.

They execute the different work packages they have defined in the first deliverable, until a Critical Design Review approximately located in the 7th or 8th week. Then, they continue with the updated project plan until presenting the product or service and delivering the Final Report at the end of the semester (13-15 weeks).

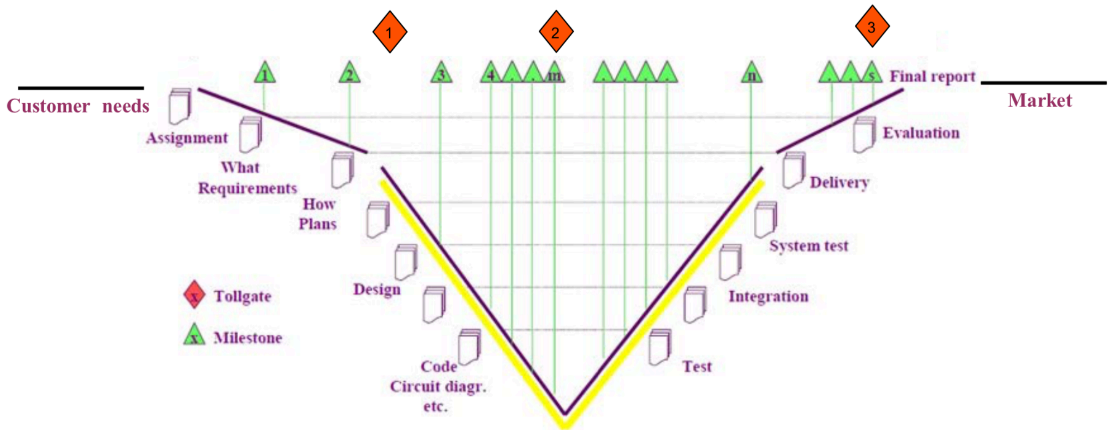


Figure 21. PDP Milestones – Weekly internal tasks results

Week	Tollgate	Deliverables
3 5	Preliminary Design Review	- Project Charter (PMBOK) - Project Management Plan
9	Critical Design Review	- Reviewed Project Management Plan
12	Preliminary FDR	
13	Final Design Review	- Reviewed Project Plan - Project Report (PPT)
13+	Project presentation + Demo	- Video (2 min) - Final Report - Business Idea / Canvas - Lessons learnt
Weekly		- Meeting minutes - Lab logbook

Table 24. PDP course schedule - Tollgates and deliverables

Weekly team meetings of up to 2 h are developed every Tuesday from 12 to 14 h. Students report their progress to their teams and to the project lead, who is in charge of leading the meeting. As an appointed secretary, one team member takes meeting minutes and action items to be addressed within the following week. Faculty role in these meetings, while staying in an observation and passive role, is to help initiate the debates if needed, and to guide the technical discussion once students presented and discussed the pros and cons of the different technical options.

There is also a 4 h tutorized work session at the lab on Thursdays from 8 to 12 h, where faculty (2 members) and teacher assistants (in some cases) guide the work of the different teams. They ask them to use critical reasoning for making the right design decisions at every step, inferring data when not readily available or to obtain it from experimentation. On week 4, during the weekly meeting, students undergo the Preliminary Design Review (PDR) in front of faculty and teacher assistants. During the weekly meeting in week 8-9, the final design of the students undergoes the Critical Design Review (CDR). These designs, before being presented at the CDR are tested in proto-boards or other type of simulations. Only after the CDR meeting, the final prototype design manufacturing and testing is triggered (i.e., print circuit boards (PCB) manufacturing). These final prototypes development is also integrated in the last weeks of the course. On week 15, the Final Review Meeting (FDR) of the whole system is carried out, and a final presentation and expo of the projects takes place, to other courses and degrees as well as faculty and teaching assistant. Company/institution representatives are invited to the final presentation. In these cases, before COVID 19, the students usually went to the companies' offices to present their projects (accompanied by professors). Since the pandemic, this has been done online.

Student's assessment is composed of a team mark. 50% is based on the process and 50% on the outcome (technical performance and complexity, solution innovativeness, prototype, final report and presentation). This overall mark is modulated for every individual student through three factors: supervisors' individual assessment, team leader assessment and peer assessment performed by the team peers using a rubric. The feedback is collected through a reflection document included in the Final Report.

The course goals and learning outcomes are:

- Consolidation and improvement of the learning outcomes of previous and simultaneous courses
- Enhancement of the CDIO skills (advanced level)
- Acquisition of generic skills (advanced level)

Learning outcomes:

- Project management and documentation
- Specific disciplinary knowledge about the project topic
- Practical design, implementation and operation skills
- Generic skills learning outcomes defined in Table 25

#	Generic Skill	Exposed	Stressed	Assessed
1	Innovation and entrepreneurship	X	X	X
2	Societal and environmental context	X	X	X
3	Communication in a foreign language (English)	X	X	
4	Oral and written communication	X	X	
5	Teamwork	X	X	
6	Survey of information resources	X	X	
7	Autonomous learning	X	X	
8	Ability to identify, formulate and solve engineering problems	X	X	
9	Ability to Conceive, Design, Implement and Operate complex systems in the ICT context	X	X	X
10	Experimental behavior and ability to manage instruments	X	X	

Table 25. PDP Generic skills learning outcomes

Approximately 170-200 students per year do it in the regular way through one of the 8-10 capstone projects proposed every semester. A total of 115 projects with 1306 students have been carried out since 2012 to 2019-2020 course. Most of them are new every semester and a few (one-two per semester) may be a continuation or second version of a previous one. A few examples of the kind of topics or briefings posed by the stakeholders are the following:

- Software application based on image and video processing to aid the rehabilitation of facial paralysis after facial nerve injury.
- Portable, non-destructive testing equipment to determine the health of "trencadís" tiles of Sagrada Familia temple.
- Improvement of several features in large-format printer sensors
- 3Cat-NXT and Distributed Satellite System projects: successive developments around a Cube-Sat platform
- Cost Effective communication payloads in Stratospheric Balloons
- Localization and monitoring of workers and assets in a Digital Factory indoor environment.
- Automatic analysis of infant sleep structure
- Chatbot for banking user-interface
- Low-cost, robust, autonomous blood-pressure measurement system for developing areas.
- Use of radar for non-contact measurement of ventilation and heart rate in newborns.
- Explore technologies for human-machine interface in vehicles.

In almost all cases, there is an initial briefing which points directly to a technical solution, although the initial requirements are a bit open (stakeholders are asked to do so by faculty), and it is a task of the students to explore client's needs around the product and define specifications in agreement with the stakeholders.

Nevertheless, in all cases, the need is already identified upfront by the company or institution and in most cases, there are clear clues about the technical solution that needs to be developed. All projects should have enough complexity in order to allow splitting them in 3-4 parallel work packages (hardware, firmware, data processing, application and user-interface software, ...) and solutions using advanced techniques and high level of abstraction are encouraged. Through the project development, the students develop a prototype able to perform a demonstration of the developed concept, including a business plan if the result is a product or service to be marketed, or at least the analysis of the engineering costs if it is an internal subsystem.

In the following pages we summarize some PDP project examples.

As the first project example and its deliverables and results, we can mention the challenge of detecting the adhesion state of "La Sagrada Familia" tiles from 2015 (Figure 22):

- Image processing to identify the individual tiles from a picture taken with a tablet (image segmentation).
- A knocking device to test the tiles and a microphone and an acquisition system to record the resulting sound (based on a Raspberry Pi).
- A signal processing algorithm to distinguish the tiles that are well adhered from those that are not.
- A user interface that allows displaying the tiles which are not well adhered in a user-friendly way.
- A test campaign with reference samples.
- A business model about the possible commercialization of the product for additional uses.

Figure 22. System to detect adherence of tiles, developed in the PDP course.

The second example consist a new and inventive software tool that relies on computer vision and machine learning for aiding the neuromuscular re-education of patients with facial paralysis through a mirror therapy (Figure 23 and 24). The software developed by the students shows a video in real time to the patient where the affected half of the face is substituted by a mirroring of the healthy side. Also, the software measures the characteristic points on the face and tracks the progress of the patient when doing some facial movements (i.e., smiling, mimicking a kiss, etc). The course was developed in collaboration with the Rehabilitation Unit of the Bellvitge University Hospital and IDIBELL (Bellvitge Biomedical Research Institute).

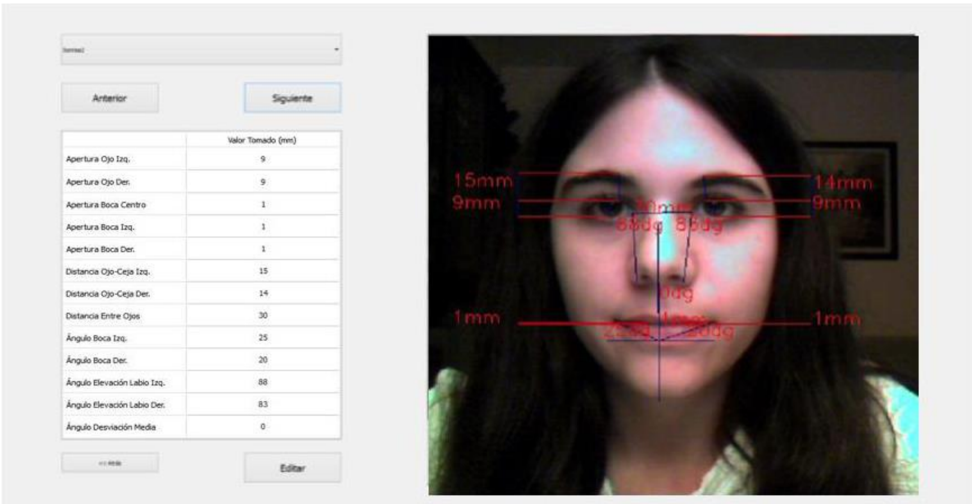


Figure 23. Automated measurement window of the aiding tool for facial paralysis rehabilitation

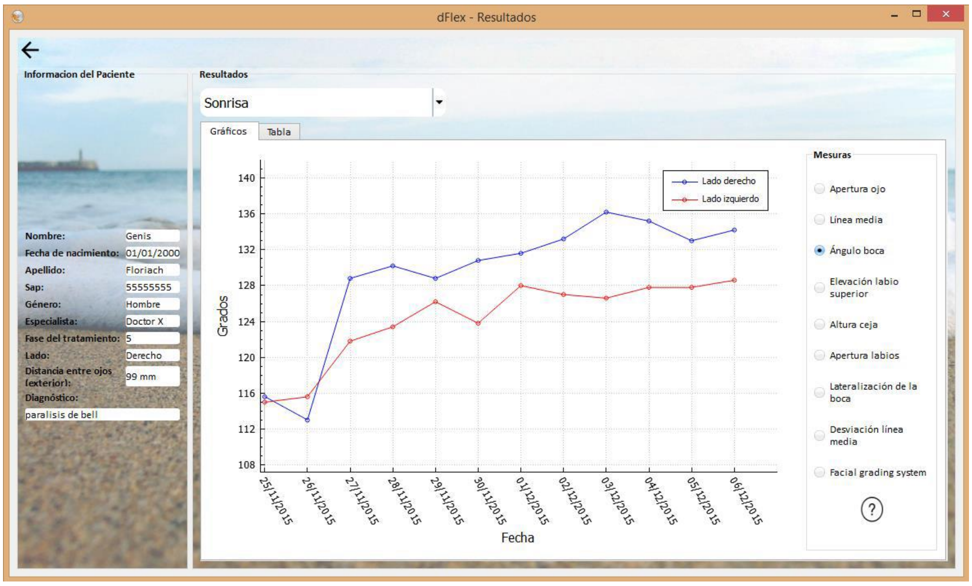


Figure 24. Software statistics windows

The third example of PDP project is Thaggus from 2017, that was created to collaborate with the Asociación Catalana de Pesca Responsable (ACPR) in order to create a product to help them investigate about the life cycle of the Bluefin tuna (Figure 25 and 26). Through a small tag attached to the fish it is possible to track and acknowledge its movements and activities for a certain time. This tag had to be competitive in price and features, compared to the ones existing in the market. The project consisted in designing an electronic device that goes along with the fish during a one-year period. During this time, it measures temperature, light, pressure and magnetic field. After one year, the tag automatically releases to the surface to transmit the data via satellite, specifically through the Argos satellite. The data received by Argos is retransmitted to the operation center (CLS), where it is processed and sent to the interested stakeholders.

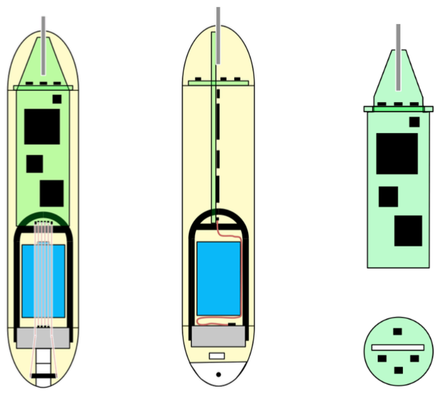


Figure 25. Final product design for tracking lifecycle of Bluefin tuna

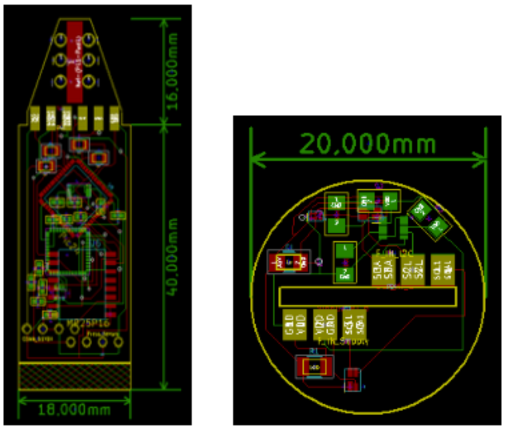


Figure 26. PCB design for tracking lifecycle of Bluefin tuna

Pig Control (2018) is the fourth example of project developed by PDP students. The project consisted in the development of a tool (Figure 27, 29 and 29) to make farmer's life easier by doing the weight control tasks of pigs in an automatic and more efficient process. The solutions aimed at reducing time and man labor costs, increasing the economic benefits.

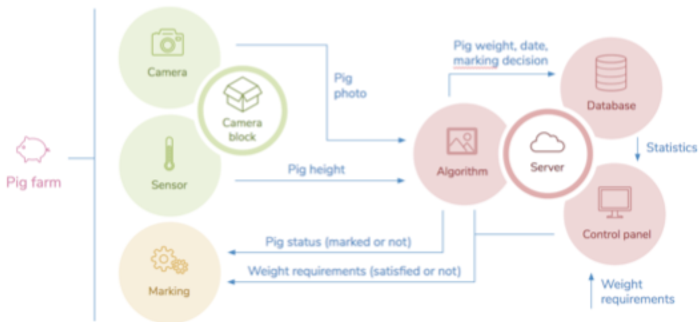


Figure 27. Block Diagram of Pig Control tool

The features of the tool the students developed are:

1. Weight calculation with an optical system installed above the feeding area.
2. Data collection in a web control panel, accessible by the farmer, with statistics and possible updates with data analysis algorithms. It is also expected to offer the possibility to make decisions about the marking process based on time, weight and quantity-based conditional orders.
3. Automatic marking of the pigs, when they accomplish certain weight requirements as indicated in the marking orders.

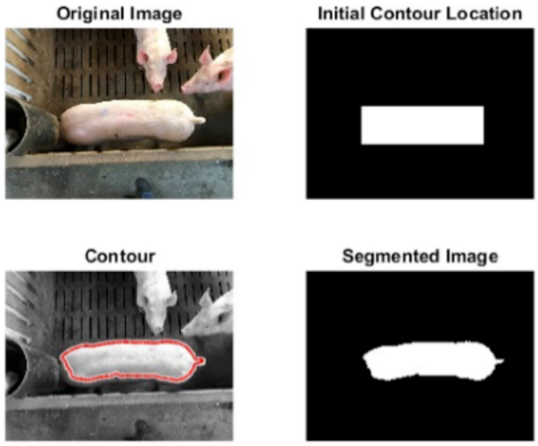


Figure 28. Pig Control masking using active shape model

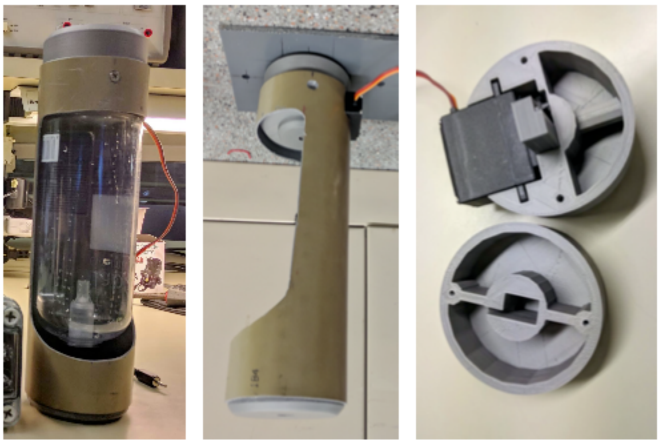


Figure 29. Pig Control prototype

The last example of PDP projects is the 3CAT-NXT project from 2019. This project focuses on the development of all the subsystems of a CubeSat (Figure 30 and 31), a small spacecraft designed to orbit the Earth and collect data. Usually satellites are very expensive, large and heavy while a CubeSat has a reduced size (made up of multiples of 10×10×10 cm cubic units) and a mass of no more than 1.33 kilograms per unit with cheaper components resulting in an affordable final price. A CubeSat has to face extreme situations such as environmental conditions, deep temperature cycles and the vibrations induced by the rocket during the launch. Working on a CubeSat introduced students to space technology. The low target cost of implementation, short preparation time and simplicity of design compared to other space projects made of this concept an excellent practical opportunity.

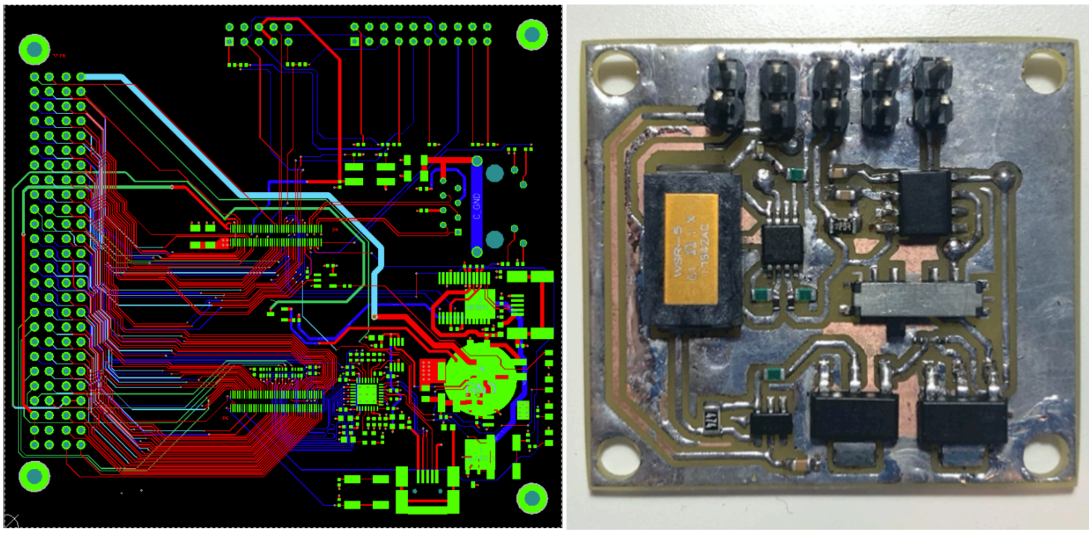


Figure 30. 3CAT-NXT PCB design and PCB

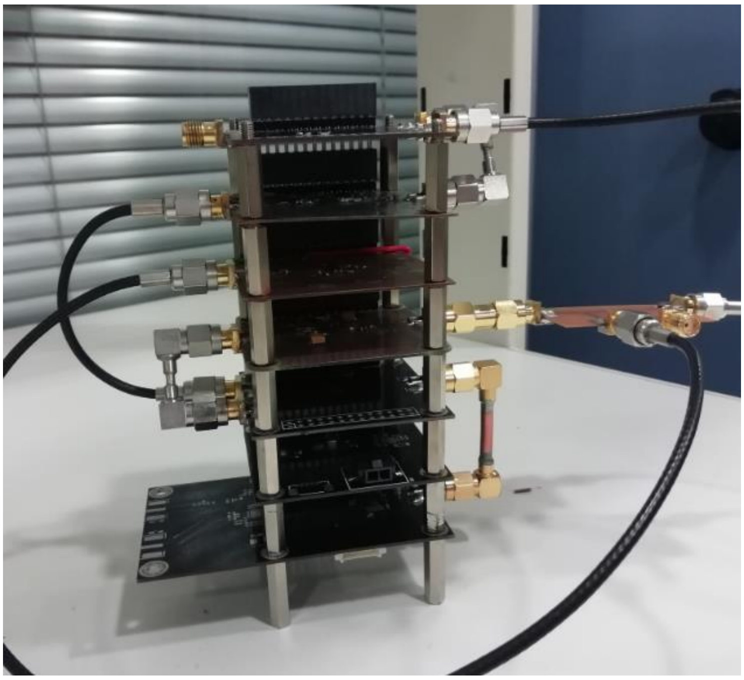


Figure 31. 3CAT-NXT communications PCB stack

All PDP projects involve a strong technical workload, with the design of several intermediate prototypes including the use of prototyping platforms (development boards, 3D printing, software development frameworks) and accurate treatment of measured data. In the last editions of the course, more than half of the projects proposed by external companies have solutions based only in software, with prevalence of data analytics, machine learning and BlockChain. It was also observed that students' preferences are shifting to these fields.

2.2. CBI – Challenge Based Innovation

The European Organization for Nuclear Research, CERN, has been carrying out groundbreaking fundamental research in particle physics for over 60 years (since 1954), and has made numerous important discoveries in the field - latest being the Higgs boson in 2012. According to CERN website (2021) "physicists and engineers are probing the fundamental structure of the universe. They use the world's largest and most complex scientific instruments to study the basic constituents of matter – the fundamental particles". In order to do this, they develop very specific and complex technologies. These technologies are purpose-built particle accelerators and detectors, which are instruments CERN scientists use to observe and record the results of their experiments (collisions of particles). The hardware and software technologies they develop for their experiments could have great potential applications and impact in the society. Some of them even can change our lives, like the case of the World Wide Web, invented by Tim Berners-Lee in 1989 at CERN.

The process of discovering the relevant societal applications for these technologies is nevertheless slow, sometimes taking even decades, and many good applications so far have been adopted through serendipitous coincidences. In order to shorten the time gap between research and its application in a structured way, a new innovation experiment called IdeaSquare was set up by CERN in 2013 in collaboration with Aalto Design Factory, a multidisciplinary research, teaching and development unit inside Aalto University in Finland.

The objective of IdeaSquare is to prove or demonstrate that applying fundamental research concepts to tackle societal challenges is of value. For this purpose, IdeaSquare hosts different activities: long-term research projects on detector R&D, different innovation-related events, hackatons and multidisciplinary university projects like CBI (Challenge Based Innovation) (Mäkinen et al., 2017, Charosky et al., 2018).

Based Innovation (CBI) is a human-centric experimental program created by CERN within its initiative IdeaSquare to host educational projects where students from different disciplines working in multidisciplinary teams, tackle innovation challenges through Design Thinking. The objective is to design solutions to complex societal problems, considering the use of CERN technologies if suitable. In collaboration with CERN mentors and coaches from their home Universities, students research, ideate and create tangible prototypes of the solutions inspired in relevant novel technologies from CERN.

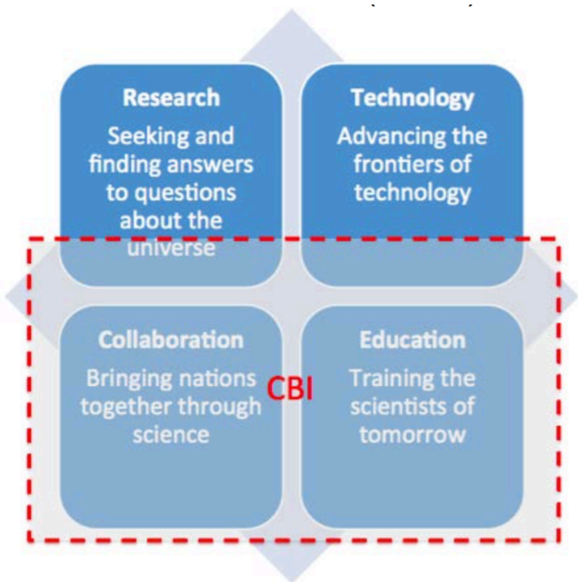


Figure 32. CBI's focus within the mission of CERN (source: CERN website)

Within CERN mission (Figure 32), CBI fits and is focused on Collaboration and Education, tapping also slightly on Technology and Research. To achieve better synergies and connections with CERN, all student teams are assigned a CERN mentor or research group they collaborate with, who helps them and guides them in everything related to technologies from this research institution.

Since 2014, three educational institutions from Barcelona participate collaboratively in this innovative educational experience. ESADE Business School, IED Istituto Europeo di Design and the Telecom Engineering School of UPC participate in CBI, developing every year the CBI Course. The three institutions from Barcelona created Fusion Point, a collaborative framework, which is also a node of the DFGN. The 8th edition is currently under preparation at the moment of writing this thesis (2021).

CBI Course Structure

Similar to the four phases of the Double Diamond design process from the Design Council (2019), and aligned with the Design Thinking methodology (Brown, 2008) and the ME310 model (Carleton & Leifer, 2009), the basic structure of CBI is composed of three main blocks: Discover, Design and Deliver (Figure 33).

Figure 33. CBI's phases (Hassi et al., 2016)

In the initial Discover phase, the teams focus on deep diving into their challenges, understanding the context, trends, benchmarking, needfinding, doing desk research and user research (observation, interviews, etc). At the end of this phase the teams define the specific need or problem they are going to tackle within the original challenge. In the Design phase the students generate multiple ideas and solutions to the problem that are prototyped in low resolution (cardboard, paper, etc) to quickly iterate and learn through user testing. After these iterations, one solution is chosen to be further developed and prototyped with higher resolution. In the Delivery phase, the selected idea is prototyped to a proof-of-concept level and the solution is developed from the technical, design and business model perspective. At the end of the project, all teams present their solutions and working prototypes in a gala event at CERN in front of scientists and universities audience, with media coverage.

Ideally the societal challenges for the course are defined in collaboration with NGOs or companies, and with IdeaSquare team. The topics of the challenges are broad and allow multiple ways to approach them, aiming for educational and learning outcomes rather the technical solutions of the projects. Since 2017's edition, alignment with UN Sustainable Development Goals (SDG) has been taken into account when defining the challenges.

Teams are usually formed by six students: two from business, two from engineering and two from design). In a few cases, some teams had only one representative of one of the institutions. In several cases, they have been added to mixed student teams from other international universities also involved in the Aalto Global Design Factory Network.

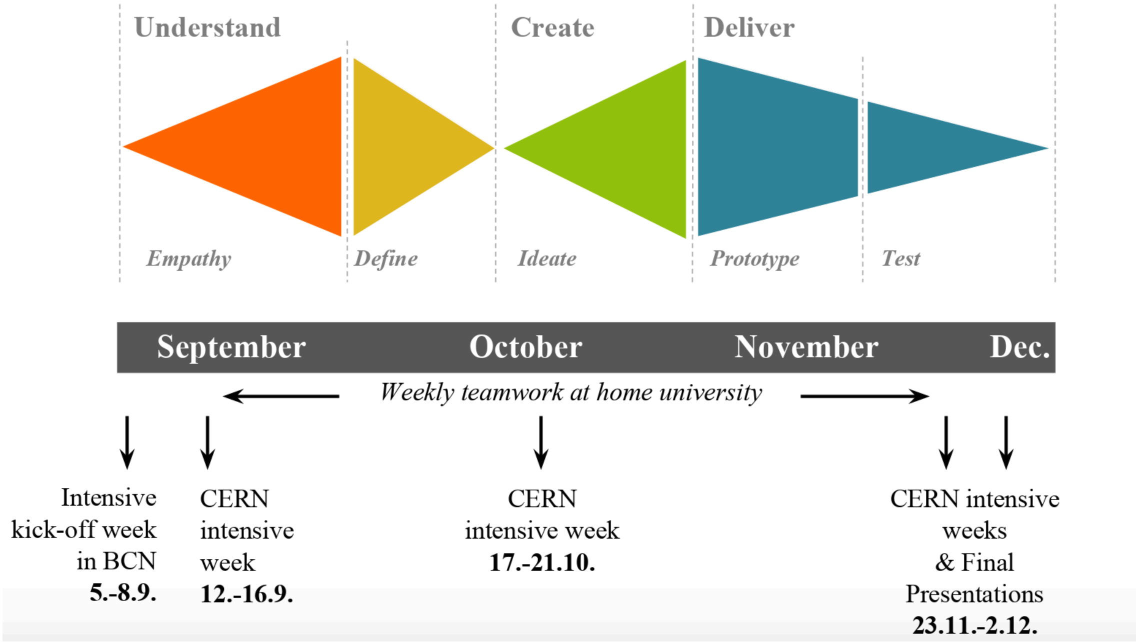


Figure 34. CBI Timeline and structure

The schedule and practical arrangements of the course have been adapted year by year. The course itself is considered prototype, that is iterated every year incorporating the learnings from each edition. In the current setup (Figure 34) there is a kick-off period, with an initial intensive week in one of the local institutions followed by a 3-5 days at IdeaSquare@CERN. Then, there is a weekly full day (8 hours) devoted to the projects in one of the local institutions along 5 weeks, followed by an intensive mid-term week 3-5 days at IdeaSquare@CERN where the ideation phase is finished in most cases. Afterwards, another set of 5 weekly days at one of the local institutions in Barcelona is devoted to converging into one solution and designing it. Finally, there is an intensive period of 10 days at IdeaSquare@CERN for solution integration and final presentation.

During the weekly course day sessions, students receive seminars/classes/workshops on specific topics along the course to develop specific knowledge/skills from the three disciplines (engineering, design & business) taught by faculty from the three institutions (ESADE, IED, UPC). Some examples of seminars covered are: Anthropological tools for innovation, Ideas for social innovation, Lego Serious Play workshop, Video prototyping, Distribution strategies for entrepreneurs, Visual presentations, IP (intellectual property) strategies, Project Management (classical approach vs. creative projects), Ideation & conceptualization, Hardware & Software prototyping, Concept testing & validation, Entrepreneurial marketing, Market validation, Financial plan & funding for new ventures, among others.

Learning objectives for students	**Practical arrangements**
• Develop highly futuristic, technologically feasible ideas that have the potential to challenge the status quo in socially and globally relevant human challenges.	• Each team have 5-6 students (except for the few editions where international collaboration with other universities were developed, where there were teams of up to

• Develop skills applying design thinking tools and methods and product design in a practical, real world project. • Develop skills in moving ideas into testable, tangible prototypes quickly. • Develop skills in interdisciplinary teamwork and communication.	9 students) coming together from two or more different universities. • The teams have a multidisciplinary combination of students who have their background in engineering (mechanical, electrical, ICT), business and design. • The project topics are confirmed and assigned during the kick-off week. Each team is paired with a dedicated CERN mentor. • Project budget is allocated for the teams for their exploratory prototypes during the process and for building the final, high-resolution prototype.

Table 26. Learning objectives and practical arrangements of CBI course

Each team at the end of the project must deliver the following items:

- Prototype of the solution (proof-of-concept)
- User testing feedback
- Demonstration of the impact of their solution
- Clear description of their link to CERN
- Final project presentation
- Well-documented project and process description
- Project video

According to the CBI Student Guidelines document, shared by the three institutions, the course learning outcomes are:

- Develop an Advanced Design project applying a methodology focused on product innovation.
- Study and guide the creation of future scenarios, based on a deep analysis of present and past, with the aim of creating new ideas applicable to the new context.
- Analyze the project considering market, society and technology, to define clear areas for new opportunities.
- Achieve the proper presentation tools to present and explain the design process, both orally and in digital format.
- Apply a strategy, making decisions for achieving innovation and quality.
- Fundament the concepts in a multidisciplinary project from a theoretical and practical perspective.
- Present and represent design ideas applying the proper techniques.
- Apply the proper digital technology for the communication and presentation of projects.
- Implement specific design research and experimentation techniques.

- Find out and study the productive processes for the fabrication of the designed projects.

The assessment of the individual students is based in the team performance (50%), the individual performance (35%) and the peer assessment (15%). The first two marks include several aspects specified in a rubric. Taking into account that the teams have, at least, a weekly coaching hour with several faculty members, we can use authentic assessment.

Feedback about the course is obtained through a specific feedback session with all students and faculty members, an individual reflection document delivered at the end of the course by the students, and several questionnaires supplied by the different institutions.

Along the 6 editions 2014-2019 of the CBI course in which our three institutions have participated, 23 different projects have been carried out. Some examples of the stated challenges and the developed solutions are shown in Table 27.

Challenge statement	Solution developed and prototyped
How might we improve the cognitive development and communication skills, and consequently the quality of life, of people with Intellectual and Developmental Disabilities through ICT?	A wearable system that helps people with Asperger's syndrome to learn about how close come to another person and how fast and loud has talked to him/her.
How can we design a viable system that allows people to restore or enhance their ability to move?	A flexible skirt with an "airbag" and a set of sensors and algorithms that triggers it when a fall is detected to prevent hip fracture in elder women.
How might we improve public health by providing safe access to water?	A low-cost sensor set-up that detects if a given well in Africa is working and a network to inform users about the well state and to manage the repairing if needed.
How might we home deliver food in a new way that maintains the food cold, at a selected temperature, ensuring its safety?	A food transportation box that combines a special isolation material, partial vacuum and RFID active tags to reduce the cooling needs and to give information on the order state to both the customer and the provider.

Table 27. Examples of challenges of CBI course (adapted from Hassi et al., 2016)

In the following pages some examples of projects developed in CBI course are explained in detail.

As a project example from CBI from 2015 we describe as follows the one based on the challenge "How might we improve public health by providing safe access to water?". The six students team explored the needs in the sub-Saharan region through local and remote contacts with NGOs and international agencies. They focused in rural areas in Ghana and first explored the needs: locating water sources, sanitizing the water, improving the safety of the water use, ... Then they explored the feasibility of using CERN-derived technologies: high efficiency solar collectors for disinfecting water, using advanced sensors to perform remote sensing of water sources, advanced filtering devices ... In all cases, they shared their findings and contrasted them with the stakeholders. At the end, and through the stakeholders' feedback, they realized that the main problem in this area was not the scarcity of water wells but the fact that more than 70% of wells were not functioning. They also found pitfalls in the way the money provided by NGOs was used. The solution they designed (Figure 35) and prototyped (Figure 36) was a low-cost sensor arrangement that was attached to the well outlet pipe (no need of modifying it). The device detected if the well was being operated through a vibration pattern detection. Also, if water was flowing through, a temperature change was detected, and an SMS message was sent to a cloud-server that displayed the well status in a synoptic map in the nearby villages. It also activated a Uber-like network of potential repairers, who would be paid through a NGO when the correct well status was automatically checked. The solution, at the end, only used the C2MON cloud solution from CERN technologies but potentially solved a relevant problem.

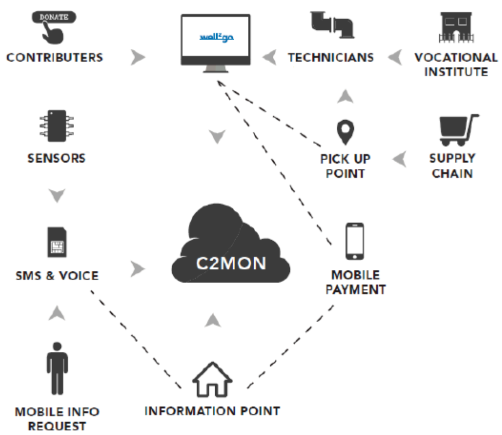


Figure 35. Block diagram of Well2go, the system designed in the CBI course (2015) to improve the safe use of water in Ghana

Figure 36. Prototype of the Well2go system

The second project example from CBI is Electree, from 2016 edition. The students' team had the challenge of how could technology help to improve the living conditions of refugees, displaced and other people in need of emergency temporary sheltering? After an in-depth research, interviews with stakeholders, NGO members, refugees and even visiting the refugee camp in Lesbos (Figure 37 and 37.1), students designed a modular plug & play extendable intelligent grid aimed at optimizing electricity distribution in scarce energy situations. Its applications extend beyond refugee camps, although it was conceived mainly for these contexts. During the research and in the visit to a refugees camp, the students realized that there were multiple initiatives already working to improve health, nutrition and education, but not about energy supply and management.

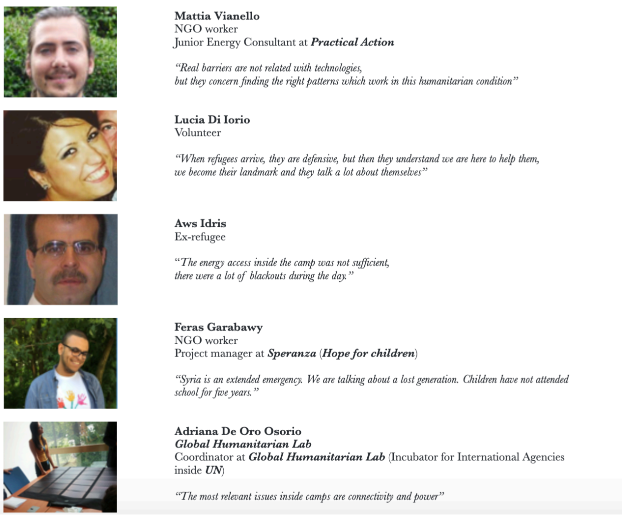


Figure 37. Interviews and key insights from stakeholders

Figure 37.1. Visit to Lesbos refugee camp

ElecTree, is a modular extendable plug-n-play intelligent grid solution (Figure 38 and 38.1), which optimizes electricity allocation by prioritizing critical needs like those of hospitals, schools, and administrative buildings while addressing needs of individual shelters; and allows the addition of multiple electricity sources. The innermost core of the network is built for extra resilience and has all the sources of electricity and important facilities of the camp (school, hospital, administrative buildings, etc). The system prioritizes the needs of these important facilities. The middle level of the network consists of hubs, which contain all the intelligent software to optimize the supply of electricity to the connected structures. While the system prioritizes important facilities, it also ensures optimal availability of electricity for individual shelters. The outermost level of the network is made of individual shelters, each of which is connected to the network through an extension cord plugged into the nearest hub.

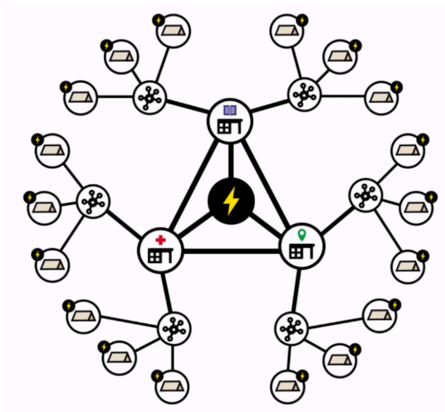


Figure 38. Electree grid with hubs, key facilities and shelters

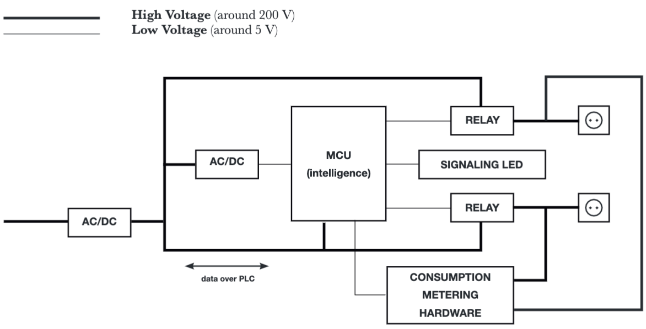


Figure 38.1. Electree general schematic of hub blocks

ElecTree is modular (components are simple modular components like hubs and extension cords, that can be built up into a network), extendable (each hub connects to multiple shelters and more hubs and electricity sources can be added as required), flexible (the network can be designed and extended according to the changing needs of the camp), intelligent (the hubs contain intelligent load balancing software that enables them to optimize the electricity supply to important buildings and shelters), cost-effective (the components cost very little to make and ship, and assembly can be done by camp volunteers and refugees).

Säker, from 2017 is the third of the chosen examples of CBI projects, who started with the challenge "How to use new technologies to revamp radiation inspection methods?". In this case, students interviewed CERN experts in radiation inspection, staff at a nuclear plant, managers of radiation therapy facilities in hospitals, public- health officers at the City-Hall, ... The conclusion of the research phase was that the highly standardized radiation inspection procedures, although could benefit from an appealing revamp through the use of new technologies (e.g., augmented reality), were a field that affected few people, and that people had strong technical skills and did not really need more comfortable methods which, on the other hand, would find difficulties to be approved by the regulation agencies. In opposition, they found through CERN contacts that there was a radiation-induced problem with high impact in the population due to the accumulated exposition to radon gas in houses and workplaces with low ventilation, which results in a relevant number of lung cancer cases. Thus, students reformulated the challenge to How might we reduce the number of lives lost to the "silent killer" Radon?

The students designed and partially prototyped a solution based on radon sensors developed at CERN which also included a service build on top of a database and a smartphone app (Figure 39) which calculates and displays (Figure 40 and 41) the accumulated exposure of an individual to radon gas using sensors and publicly available information and also takes into account the individual susceptibility based on family history of lung cancer and other environmental factors (smoking, ...) and that could include genetic data in the future.

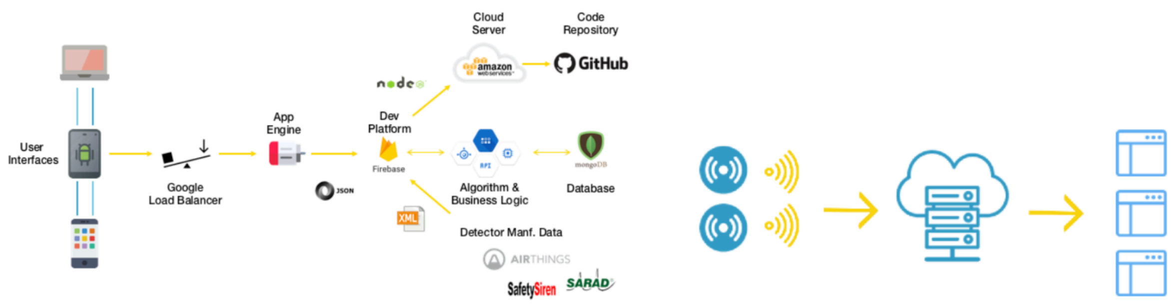


Figure 39. Säker system diagram for Radon detection and information

The platform designed by the students consist of a of radon detectors' network that provides personal risk assessment and offers services of personalized care and mitigation strategies. Säker solutions is composed of: 1. Monitoring of Radon based on location and sensors' network, 2. Sensitivity analysis of Radon based on personal information (demographics like gender and age, lifestyle decisions like smoking, house cleaning...) and genetic information (like family history or DNA test) and 3. Information shared with other stakeholders.

Figure 40. Säker App showing the user interface

Figure 41. Säker App showing the user interface

The fourth CBI project example called Sentra, from 2017 that worked on the challenge "How might we use immersive technologies to design realistic, productive and memorable learning experiences for humanitarian missions in risky environments?". The students' team designed a solution to psychologically train the people who need to be prepared for acting properly in emergency sanitary situations, such as MSF (Médecins Sans Frontières -Doctors Without Borders), firefighters, paramedics...One of the insights from the in-depth research phase identified by the students was that these organizations need to have amazingly trained and prepared doctors and logisticians working for them, and replicating the scenarios of emergency or catastrophic scenarios is timely, not easy, not realistic and not cheap (Figure 42).

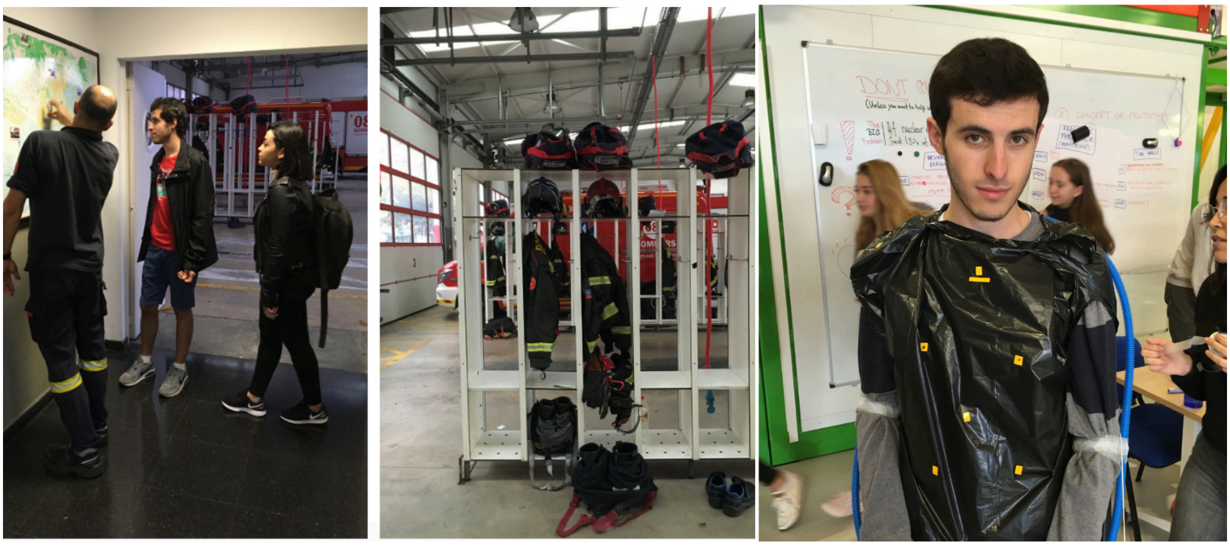


Figure 42. Sentra interviews with firefighters and early dirty concept prototype

This is why they developed SENTRA (Figure 43), a tool that will help train these professionals faster, with a lighter emotional charge regarding high stress missions, and enhance their performance on field. Students' solution is aimed at training professionals' instinct and situational response to foreign events through a full body suit with sensors, thermal devices and vibration motors. Once worn, it will monitor relevant body information, like the heart rate or the electrodermal activity and provide a physical sensation (pressure, heat, cold, vibration,...). Furthermore, SENTRA comes with VR glasses to develop a full immersion experience for the user, entering a new world with specific situations and scenarios for training. The tool can be adapted, and content can be developed for training different professionals, like doctors, firefighters, rescue professionals, etc.

Figure 43. Sentra final prototype and design

The system is connected to a central computer (Figure 44) and with high-level algorithms, the scene can change in real-time depending on how nervous or relaxed the user is in that precise second. It works with an artificial intelligence (AI) software that can perform different actions based on different inputs.

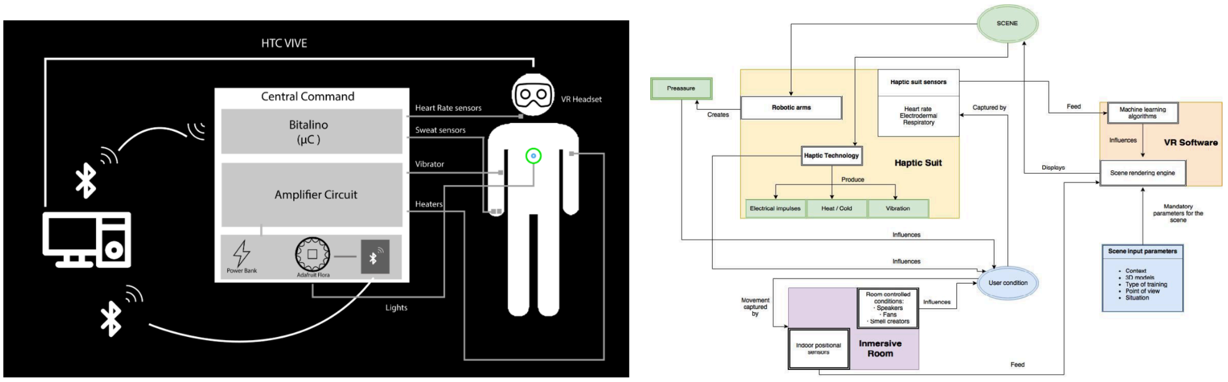
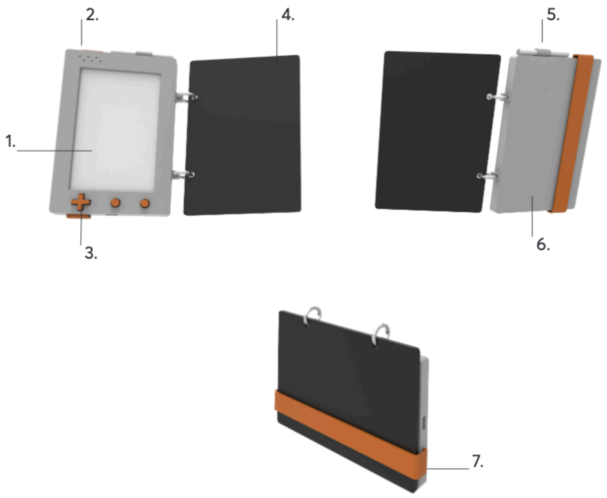


Figure 44. Sentra training system block diagram

The last example of CBI project is LEAF, from 2018 addressing the challenge "How might we bring primary education to the children of Nomadic families between the ages of 5 and 12 by providing a learning solution that moves with them so they can improve their future opportunities?". The original challenge was just the Sustainable Development Goal (SDG) 4 Quality Education. The studentes redefined the challenge after speaking with people from UNESCO in Geneve during one of the periods at CERN, and also with people that manage education programs in Niger.

LEAF focuses on creating an educational solution for Niger, addressing the primary school education on a large demographic group in the country, the Nomadic populace, that is frequently left out of the traditional education system of the country. The students focused on the Fulani people (around 2 million people), the largest nomadic group in the country with a pastoral lifestyle traveling with the livestock around the country. Due to this, they cannot fully participate in education programs of NGOs or the government.

The solution consist of a system composed of resistant low-cost and low-consumption tablets (Figure 45) with the ability to setup dynamically its own networks locally between students and teachers without relying on traditional infrastructure.



1 - 7.5" eInk Screen: Low Power Consumption display of immersive and informative graphics to make learning more intuitive and interactive.
2 - Built in Speaker: Audio capable system to help students with learning to read/write through audio prompts and to keep students engaged.
3 - Durable Navigation Buttons: D-Pad and 2 Selection Buttons provide flexible and durable system navigation.
4 - Writing Surface: Slate attached to the device provides a reusable writing surface for the students to perform writing exercises and arithmetic.
5 - Chalk Holder: Chalk storage to keep the necessary writing implement with the tablet at all times.
6 - Solar Panel: Built in charging capability allows the device to work without requiring electric infrastructure.
7 - Carrying Strap: To make the device easier for children to transport and hold during their lessons and keeps the tablet from opening when not in use.

Figure 45. LEAF tablet design and features

ZigBee (low-power communication protocol that supports short range communication) and LoRa (low-power long-range communication protocol) are the technologies used by the students to enable connecting multiple Fulani Tribes, and more importantly the Fulani students to teachers (Figure 46, 47 and 48). Thanks to this solution, Fulani children would be able to learn remotely with the support from their teachers.

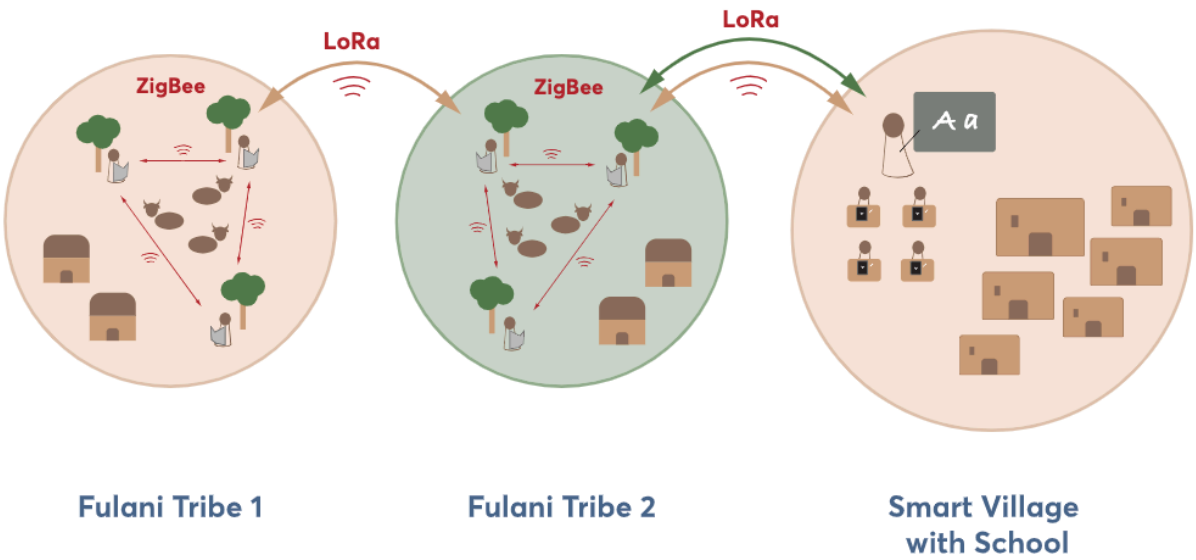


Figure 46. LEAF solution based on ZigBee and LoRa technologies

Figure 47. LEAF early prototype

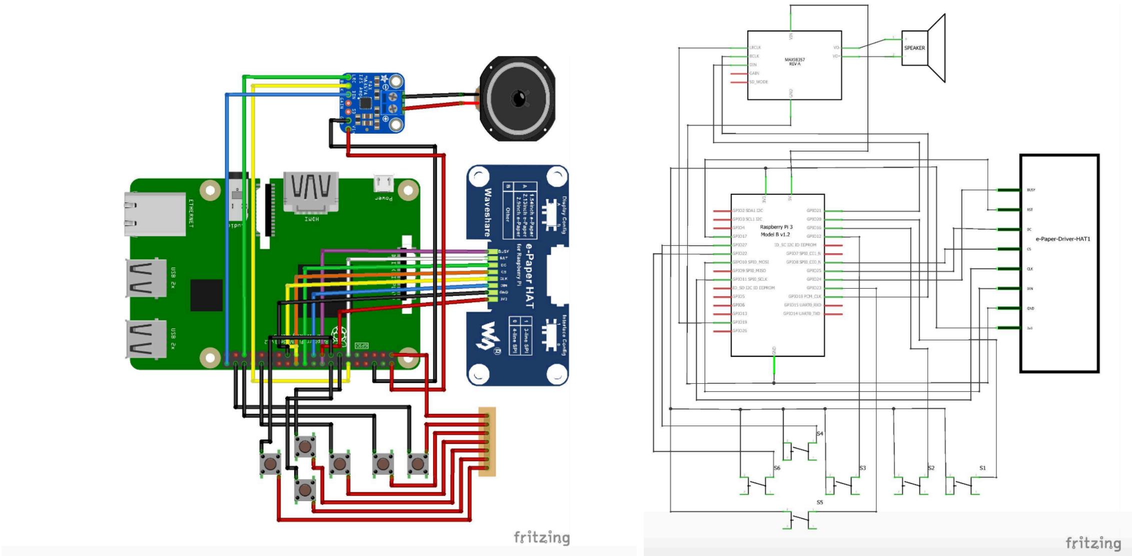


Figure 48. LEAF technical solution diagrams

Almost all CBI challenges and solutions have a similar story of in-depth understanding and selecting the relevant need to be solved, and solution development through intense user feedback and testing. Although, from the technological point of view, in many cases the solutions may not be so appealing. The final reports and videos of the projects can be found at http://www.cbi-course.com/, under the "Projects" section.

2.3. CBI and PDP comparison

Several relevant aspects are worth mentioning when comparing CBI and PDP courses, as they have interesting differences and also similarities.

Regarding the context, in both cases the courses provide an environment close to a real-world activity, being more suitable to obtain deep learning outcomes and develop transversal skills and competences, as shown in literature (Dym et al., 2005), than regular theory-lab-problems-exam subjects. There are, however, some differences. In PDP projects, the context is known and the multidisciplinarity is not really as such. They are all engineering students, with the limited difference to minors into ICT engineering disciplines. On the other hand, in CBI, the context is unknown; all the students (mainly the engineers) are out of their comfort zone and have to learn to work with others.

Course	Pedagogical method for innovation education	Innovation approach	Team composition	Learning outcomes
PDP Product development project	Project-Based	NPD (New product development)	Single disciplinary (engineering students only)	• Project management and documentation • Specific disciplinary knowledge about the project topic • Practical design, implementation and operation skills • Generic skills learning outcomes: Innovation and entrepreneurship, Societal and environmental context, Communication in a foreign language (English), Oral and written communication, Teamwork, Survey of information resources, Autonomous learning, Ability to identify, formulate and solve engineering problems (Bragós et al., 2010)
CBI Challenge based innovation	Challenge-based	Design Thinking	Multidisciplinary (engineering, design and management)	• Develop highly futuristic, technologically feasible ideas that have the potential to challenge the status quo in socially and globally relevant human challenges. • Develop skills applying design thinking tools and methods and product design in a practical, real world project. • Develop skills in moving ideas into testable, tangible prototypes quickly. • Develop skills in interdisciplinary teamwork and communication. (Hassi et al., 2016)

Table 28. Course comparison: PDP vs. CBI

As observed in Table 28, the main differential aspects of these courses are the pedagogical methods (Project-based vs. Challenge-based), the innovation approach (NPD vs. Design Thinking), the team composition (single disciplinary vs. multidisciplinary) and the learning outcomes. Regarding the latter, it is interesting to highlight that even both courses learning outcomes mention some innovation competences, PDP does mention innovation as a learning outcome, while CBI does not. Also, PDP focuses more on project management, engineering design and implementation and CBI focuses more on ideation and prototyping.

While in CBI course students devote four-five weeks to needfinding, four more weeks to ideation (including low resolution prototyping and testing) and only four weeks to final solution prototyping, the usual structure of PDP projects at Telecom BCN is two- three weeks to fix specifications from initial requirements, six weeks to subsystems design and implementation and five weeks to system integration and refinement. As a consequence, the technical deepness and complexity of solutions is higher in PDP projects than in CBI projects, but the degree of awareness of what are the real needs, the context (business, user…) of problem being solved and what does the user expect from it is clearly lower in PDP than in CBI.

Regarding the technical complexity and deepness, in PDP projects is higher and there are strong learning outcomes on the science and technology involved in the solution, although this is not the main goal of the subject. In the CBI course, due to the lower workload devoted to the technical solution (less time, only 2 engineers per team), the complexity and deepness are lower, although relevant. The goal is to provide a final prototype able to provide a proof-of-concept of the critical parts of the solution.

Regarding the user-needs awareness, in PDP course is usually low, with some exceptions. Although this aspect has improved since projects have external stakeholders for almost all projects, the specifiers are usually engineers and not final customers, and the projects are often technology driven. There are some exceptions in PDP projects, when interlocutors are not engineers or technicians but end users (only 1-2 projects out of 6-9 per semester). Some students in PDP teams can be even only devoted to technical tasks and miss the user/market orientation of the product and the business aspects. On contrary, in the CBI course, the user awareness and context immersion are extremely high, as all students (including the engineering ones) engage in user and market research. Thus, it is prioritized the potential innovative impact of results rather than technology development, which takes a secondary role.

There is an issue that has been identified by the professors and has to be controlled: engineering students tend to apply technological solutions in the low-resolution prototyping phases during needfinding and ideation, where they are still not needed and could distort the user-centric approach. Also, engineering students (and even teachers) use to reveal technology limitations in the ideation phase, where disruptive solutions that go beyond the currently possible solutions could appear.

Concerning the project planning and documentation, it follows a strict protocol in PDP projects, using an adapted version of LIPS and PMBOK models as mentioned above. Although it is presented to the students as a way of ensuring the project success, it is often seen as bureaucracy and as an obligation. On the other hand, in CBI course, documentation and planning are not so strict and are mostly based on presentations, videos and low- resolution prototypes, with a lot more iteration and interaction with users than the classic projects. The method can be considered close to the extreme-agile software development method.

In PDP projects, the students feel stress on the need of completing the assigned sub-system on time and on dealing with incidences. In CBI projects, the stress is put in the first two thirds of the course in the collaborative sense making (all students from all disciplines participating in all phases) and only in the last third, on the delivery of specialized outcomes.

Regarding the quality of the results, both subjects are highly motivating, and the project results are usually good or very good, often outstanding. In the PDP project, the students' commitment is medium to high and there are only a very few cases every year of individual students not getting good results and marks, even failing the subject. In the CBI course, the results are usually outstanding. There is a potential bias factor in the fact that the students compete to be part of this course and some of the best ones are chosen, but there is in any case a very high commitment and also the added pressure (and incentive) of presenting at CERN. Also, in PDP projects proposed by external institutions the pressure and commitment are high. But in PDP projects proposed by faculty members, the students feel that are among peers and the context is closer to a regular subject.

The human resources allocated to the projects is quite similar. Although the local teams in CBI courses are smaller (5-6 students vs 9-12 students), they devote more time to the project thanks to the intensive weeks at IdeaSquare.

Chapter 3 - Research methodology

3.1. Methodology

The experimental part of this thesis aims to analyze, identify and compare the engineering students' innovation competences acquired in two different type of experiential learning courses developed at Technical University of Catalonia (UPC) between the years 2015 to 2019. The objective is to understand how to better develop innovation competences in engineering students, in order to draw conclusions to better design educational strategies with this purpose.

The compared courses used as framework for the research are the PDP course (Product Development Project) and the CBI course (Challenge Based Innovation) developed by UPC Telecom described above.

The research followed a phenomenographical approach, described as "... the limited number of qualitatively different ways in which students experience, conceptualize, understand, perceive, apprehend, etc., various phenomena and aspects of the world around" (Marton, 1994). According to Marton (1986), "Phenomenography is an empirical research tradition that was designed to answer questions about thinking and learning, especially for educational research."

As the research aims to analyze whether an educational practice makes a difference (CBI course vs. PDP course) for developing innovation competences, an experimental design research approach was used. As described by Creswell (2012), experimental designs (also known as intervention studies or group comparison studies) are "procedures in quantitative research in which the investigator determines whether an activity or materials make a difference in results for participants". Our research assesses the impact by having one group going through a set of activities (an intervention, in this case CBI course) and with-holding these activities from another group (in this case the PDP group).

Strictly speaking, as we are not able to address some of the key characteristics of "true experiments" as defined by Cohen et al. (2012), we must refer to a quasi-experiment. One of the characteristics that we don't have and would be desirable is a pretest of the groups to ensure parity. We have run a post-test only and a comparison of the results of the two groups.

The methodology of this research is based on both qualitative analysis and quantitative analysis, combined in a mixed methods research (Creswell, 2012).

For the qualitative analysis, out of the six different types of methods proposed by Prus & Johnson (1994) to assess "professional skills" in students, "measures of attitudes and perceptions" was chosen for this research. More specifically, we used self-reports, named reflection documents in these courses, produced by students as part of the final deliverables of both courses and portfolios (projects) were analyzed and compared. Bandura (1982) found that reflective essays written by students can be a good predictor of design performance, as self-efficacy (belief in one's own abilities toward a given task) play a fundamental role in effectively executing innovation.

The qualitative analysis of the personal reflection documents consisted of a content analysis, described by Weber (1990) as a process "by which the many words of texts are classified into much fewer categories" with "strict and systematic set of procedures for the rigorous analysis, examination and verification of the contents of written data" (Flick 1998).

Regarding the quantitative analysis, an online survey was performed using the INCODE Barometer Rubric 5 (Figure 49), as we aimed also to analyze and compare the engineering students' innovation competences based on their self-perception, acquired in the two different analyzed courses.

		Not Observed / not demonstrated	Very poor	Needs to improve	Pass	Good	Excellent
		0	1	2	3	4	5
	Individual						
1	I present ideas that are suitable for the task						
2	I present creative ideas						
3	I present new ways to implement ideas						
4	I evaluate the advantages and disadvantages of actions						
5	I identify relationships among different components of the task						
6	I face the task from different points of view						
7	I use available resources ingeniously						
8	I foresee how events will develop						
9	I show enthusiasm						
10	I persistently pursue the goals						
11	I take daring yet reasonable risks						
12	I orient the task towards the target						
	Interpersonal						
13	I transmit ideas effectively						
14	I listen to teammates						
15	I establish constructive group relationships through dialogue						
16	I collaborate actively						
17	I contribute to group functioning						
18	I take initiatives						
19	I drive others to act						
20	I face conflicts with flexibility to reach agreements						
	Networking						
21	I apply ethical values						
22	I take into account the implications of the task for society						
23	I am able to work in multidisciplinary environments						
24	I am able to work in multicultural environments						
25	I use networking contacts to reach goals						

Figure 49. INCODE Barometer Rubric 5. Self-assessment of innovation competence performance. Adapted from Watts et al., 2013

Our empirical research complies with the conditions defined by Gallivan (1997):

- "at least two different methods are used for collecting data
- at least one of the data collection methods is qualitative
- at least one of the data collection methods is quantitative
- both qualitative and quantitative data are presented
- both qualitative and quantitative data are analyzed
- the research addresses a theoretical question rather than providing description only"

Thus, we can define the methodology of this study as a mixed methods research, followed for collecting, analyzing, and mixing both quantitative and qualitative methods in a single study to understand the research problem (Creswell & Plano Clark, 2011).

3.2. Participants and sampling

The strategy followed to define the sample to study was a purposive sampling, defined by Cohen et al. (2007) as selecting the cases based on their "typicality or possession or characteristics being sought". We aim to have homogeneous samples (Patton, 1990), with the purpose to describe two particular subgroups in depth: students that follow PDP vs. students that follow CBI course.

The characteristics that we were looking for were students who went through a project-based course working on real projects for companies, external institutions and/or social challenges aiming to develop a technical solution and a prototype.

In this case, as described previously we analyzed results and compared two groups of students of Telecom Engineering from Technical University of Catalunya:

- Students that have taken the capstone project course PDP (Product Development Project), called Advanced Engineering Project from 2015 to 2019 following a classical product development approach.
- Engineering students that have taken the CBI (Challenge Based Innovation) course from 2015 to 2018 following a challenge-based education approach using Design Thinking.

The population of interest can be fairly determined as all Telecom students must take one course or the other.

It is important to highlight that by default all students should initially take the PDP project course, but the CBI course is offered as an alternative way of doing it. For being accepted to CBI they need to proactively opt for it, and they have to present their grades and a motivation letter. This poses a potential risk for the study, as CBI students may already have a certain bias or motivation to better develop innovation competences versus PDP students.

This risk is also mitigated as PDP course runs twice a year (1st and 2nd semester) and CBI only runs once a year (1st semester), being that students taking the project-based course in the 2nd semester cannot opt to attend CBI.

The proportion of female engineering students both in PDP and CBI is 17%, slightly below Technical University of Catalonia 25% average (Farreras, 2019). Age (20-22 years), cultural (almost all Catalan) and socio-economic background is pretty homogeneous in both courses, with the only possible bias being in CBI the need for affording only the cost of low-cost flights and meals for the 3 trips to Geneva for the CERN periods.

3.3. Sample size

Although there is not a fixed answer in what is the minimum number of participants or cases to define a sample for quantitative, qualitative study or mixed methods, literature suggests a rough estimate for educational research of approximately 15 participants in each group in an experiment and 30 participants for a correlational study for a statistical procedure (Creswell, 2012, Cohen et al., 2007).

The sample size is in both cases (PDP and CBI) bigger than the 30 participants suggested in literature. In the quantitative survey, the total number of respondents was 81, being 49 from PDP and 32 from CBI. In the qualitative analysis, 38 from PDP and 39 from CBI reflection documents and project results were analyzed. Thus, we could say that it is enough to withdraw relevant conclusions.

3.4. Qualitative research: Content analysis

3.4.1. Data collection

All personal reflection documents delivered and final project reports between the researched period (2015-2019) researched were collected, being a total of 77 documents analyzed with 38 from PDP and 39 from CBI (Table 29). As observed in Figure 50, in CBI, there is a similar number of analyzed every year but in PDP, this number varies from 2 in 2016 to 15 in 2017. The reason of having less reflection documents in the first years for PDP is that only projects with external stakeholders (companies or institutions) have been chosen for the analysis. These were gradually increased in the following years. The reason for not having CBI documents in 2019 is because at the moment of doing the analysis, the 2019 course was ongoing. Thus, CBI students from that year haven't delivered their projects and personal reflections yet.

In these documents, students were asked to reflect on their process, lessons learnt, project's results and future/next steps of their projects through general and broad questions. In neither case (PDP nor CBI) students were asked specifically to reflect on innovation competences and/or their perception about them.

	PDP	CBI
Year	**Nº of reflection docs**	**Nº of reflection docs**
2015	3	9
2016	2	10
2017	15	10
2018	10	10
2019	8	-
TOTAL	**38**	**39**

Table 29. Total number documents analyzed per year and course

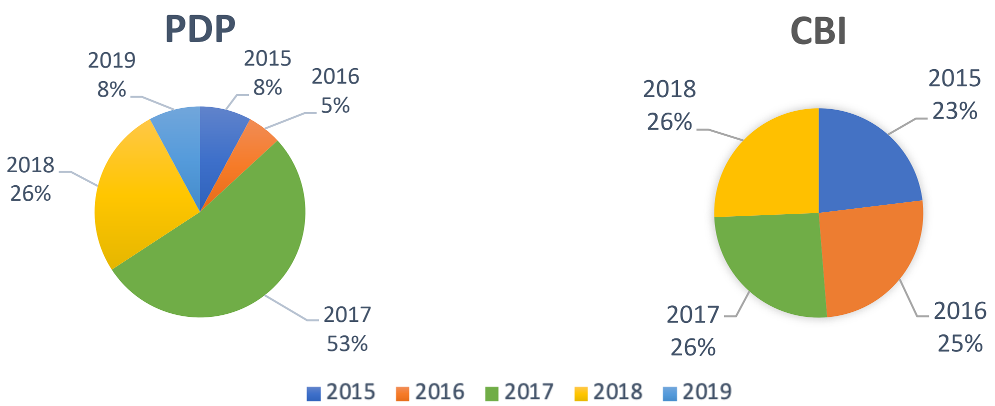


Figure 50. PDP and CBI Percentage of documents analyzed per year

3.4.2. Data analysis

The analyzed data are the 77 reflection documents produced by the students, with the aim of identifying mentions, insights, conclusions, keywords and learning outcomes related to innovation competences through content analysis and data coding.

The sought data in the documents was evidence (direct or indirect) of innovation competences discussed in research and literature previously defined (Table 1), synthetized and prioritized in Table 30: CDIO, ABET, ENAEE – EUR-ACE®, NESTA, INCODE and FINCODA projects. The competences identified in the literature review (Table 30) were merged and structured into a framework (Table 31) that synthetizes and condenses all the competences identified in the literature into 8 themes or categories composed of 26 innovation competences. The framework was developed through an iterative process of analysis and coding of the documents done by the author of this thesis, with iterations by the co-authors of the research article associated to this part, later discussing its validity and utility, evolving it into the final set of themes and codes innovation competences (derived from literature review) and used for the analysis of the documents (Table 31).

The process followed for the content analysis was the one described by Tesch (1990) and Creswell (2007). Using a convergent approach, the coded qualitative data was descriptively analyzed and the frequency of occurrence of these codes was counted (Creswell, 2012).

Finally, a total of 1665 segments were coded, 790 (47%) in 38 documents from PDP and 875 (53%) in 39 documents from CBI.

To analyze the data, the software for text analysis MAXQDA was used, as it enables to combine both qualitative and quantitative procedures. It allows identifying specific words and expressions as codes, organizing the codes by themes and counting and classifying them. The analysis consisted of reviewing all the texts imported in the software and manually marking all expressions that would have the same meaning than a given code under its category.

As a result of the qualitative part of the research, an article was submitted to the European Journal of Engineering Education (First submission on 19th July 2020. Under second review since 8th March 2021), with the title "Developing Innovation Competences in Engineering Students: Two Approaches Comparison".

SOURCE	PROPOSED SET OF INNOVATION COMPETENCES	
INCODE The Innovation Competencies Development project (Watts et al., 2013, 2014)	• Individual: creativity and critical thinking • Network: networking and impact	• Interpersonal: teamwork and leadership
FINCODA Framework for Innovation Competencies Development and Assessment (Marin-García et al., 2016)	• Creativity • Critical thinking	• Intrapreneurship: initiative, teamwork and networking
ABET	**Process skills:** • Communication	**Awareness skills:**

Accreditation Board for Engineering and Technology (ABET, 2017, Shuman et al., 2005)	• Teamwork • ability to identify and solve ethical dilemmas	• Social and global factors impact understanding • Contemporary issues knowledge • Ability for lifelong learning
CDIO Syllabus v2.0 Statement of Goals for Engineering Education (Crawley et al., 2011)	**Competences related with innovation:** • Analytical reasoning and problem solving • Experimentation • Investigation and knowledge discovery • System thinking • Teamwork	• Communication • External societal and environmental context • Enterprise and business context • Leading engineering endeavors • Engineering entrepreneurship
ENAEE – EUR-ACE® European Network for Accreditation of Engineering Education	• Knowledge and Understanding • Investigations	• Engineering Practice • Making Judgements • Communication and Team-working
NESTA National Endowment for Science, Technology and the Arts of United Kingdom (Chell & Althayde, 2009)	• Creativity (imagination, connecting ideas, tackling and solving problems, curiosity) • Self-efficacy (self-belief, self-assurance, self-awareness, feelings of empowerment, social confidence) • Energy (drive, enthusiasm, motivation, hard work, persistence and commitment)	• Risk-propensity (a combination of risk tolerance and the ability to take calculated risks) • Leadership (vision and the ability to mobilize commitment)

Table 30 - Selection of innovation competences identified for the development of engineering education according to different standards

1. CREATIVITY • User awareness • Uncertainty management • Idea generation • Design Thinking	2. PLANNING AND MANAGING A PROJECT • Planning • Organization • Time management
3. LEADERSHIP & ENTREPENEURSHIP • Entrepreneurship • Leadership/Initiative • Energy	4. TEAMWORK • Communication • Coordination • Multidisciplinary

• Risk-propensity	
5. IMPACT • Business sense • Social impact • Sustainability	6. PERSONAL & PROFESSIONAL SKILLS • Self-efficacy • Critical thinking • Self-awareness for professional life
7. NETWORKING • Networking	8. EXPERIMENTATION & KNOWLEDGE DISCOVERY • Problem solving • Technical solution/Technology • Investigation & Knowledge discovery • Experimentation

Table 31 - Innovation competences themes and code system

3.5. Quantitative research: Self-perception

The INCODE survey was sent to 959 students, who have taken PDP or CBI course during the period of 2015 to 2019. Obtaining an average response rate of 8,4%.

3.5.1. Data collection

To collect the data, the INCODE Barometer was used, sending via email to the students, who had taken either CBI or PDP, a link to a Google Forms with the Rubric 5 of the INCODE Barometer (Watts et al., 2013), asking them to reflect their self-assessment on innovation competences acquired. Students had to assess on a scale from 0 (Not observed / not demonstrated) to 5 (Excellent), their level of agreement with the 25 statements related to innovation competences, structured in 3 levels (Individual, Interpersonal and Networking), as observed in Figure 49.

The total number of respondents was 81, being 49 from PDP and 32 from CBI. The number of responses per years was: 11 in 2015 (14%), 9 in 2016 (11%), 17 in 2017 (21%), 18 in 2018 (22%) and 26 in 2019 (32%) as shown in Figure 51.

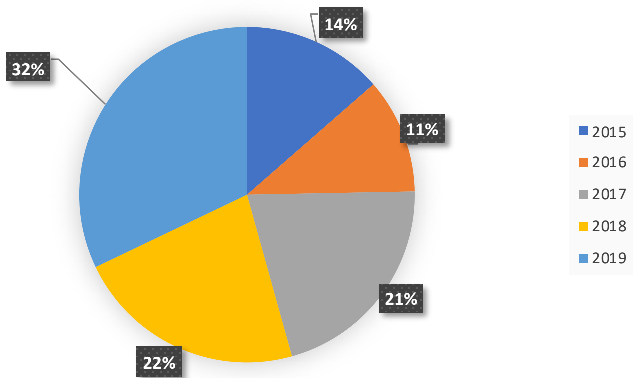


Figure 51. Respondents to INCODE Barometer percentage per year

From the total sample of respondents (81), there is 73% (59) males and 27% (22) females (Figure 52) which is a little above the percentage of females taking the PDP and CBI course (17%).

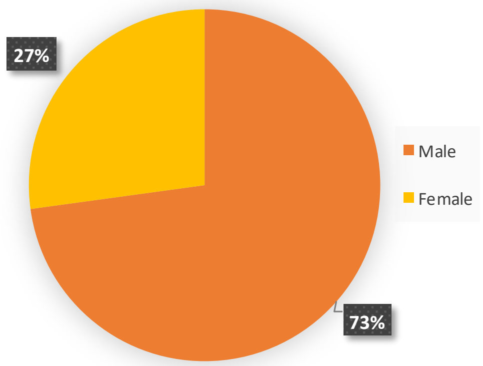


Figure 52. Respondents to INCODE Barometer percentage of males and females

3.5.2. Data analysis

The results of the INCODE Barometer survey were analyzed using JASP version 0.11.1, an open-source statistical analysis tool developed by University of Amsterdam, The Netherlands. The independent samples t-test was used to estimate the effect size and test the one-sided alternative hypothesis that the mean of the answers of CBI group are bigger (or smaller) than the mean of the answers of PDP group for each question. The sign of the difference between means was used to determine the sense of the hypothesis tested. The percentage of the difference among means has been calculated respect to the CBI mean value for each case. To consider a hypothesis as validated (so discarding the null hypothesis), we have considered the usual threshold of $p<0.05$, although we have mentioned in several cases differences with p-value between 0.05 and 0.1 as "moderately significative" or "non-negligible". As a result of the quantitative part of the research, an article was published in the International Journal of Engineering Education, Vol. 37, No. 2, pp. 461–470, 2021 with the title "Investigating Students' Self-Perception of Innovation Competences in Challenge-Based and Product Development Courses". The article can be found in the Annex of this thesis.

Chapter 4 – Results and discussion

4.1. Results of the qualitive research: Content analysis

As observed in Table 32 and in Figure 53, out of the eight innovation competences groups, the ones that have more mentions by the students on average, considering both PDP and CBI are Experimentation & Knowledge Discovery with 19,2% (23,9% PDP and 15% CBI), Teamwork with 18,4% (16,1 PDP and 20,5% CBI) and Personal & Professional Skills with 16,5% (equal for PDP and CBI). Then it comes Creativity with 14,2% (9,2% PDP and 18,7% CBI), Planning and Managing a Project with 12,3% (22,2 % PDP and 12,3% CBI) and Leadership & Entrepreneurship with 9,8% (5,8% PDP and 13,4% CBI). Finally, there is Impact with 4,9% (3,4% PDP and 6,2% CBI) and Networking with 4,7% (2,9% PDP and 6,4% CBI).

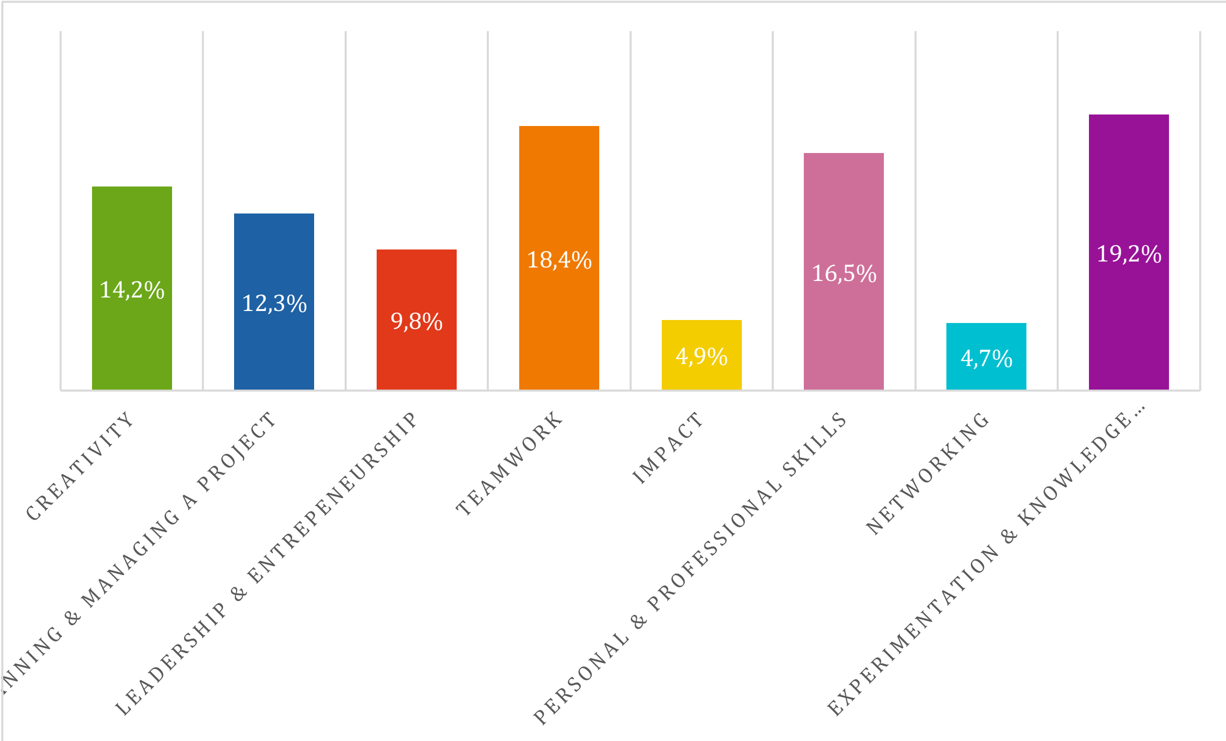


Figure 53. Total average PDP and CBI Innovation competences themes percentages based on the total number of coded segments (SUM 100%)

Table 32 shows where the bigger percentages of coded segments are, to visualize which innovation competences are more present in students' reflection documents in each course.

	PDP	CBI	Total
CREATIVITY	**9,2%**	**18,7%**	**14,2%**
User awareness	2,7%	4,2%	3,5%
Uncertainty management	5,9%	7,4%	6,7%
Idea generation	0,6%	6,1%	3,5%
Design Thinking	0,0%	1,0%	0,5%

PLANNING AND MANAGING A PROJECT	**22,2%**	**3,4%**	**12,3%**
Planning	4,6%	0,1%	2,2%
Organization	13,0%	1,9%	7,2%
Time management	4,6%	1,4%	2,9%
LEADERSHIP & ENTREPENEURSHIP	**5,8%**	**13,4%**	**9,8%**
Entrepeneurship	0,0%	2,4%	1,3%
Leadership/Initiative	1,6%	5,7%	3,8%
Energy	4,2%	5,0%	4,6%
Risk-propensity	0,0%	0,2%	0,1%
TEAMWORK	**16,1%**	**20,5%**	**18,4%**
Communication	6,2%	3,8%	4,9%
Coordination	9,7%	5,0%	7,3%
Multidisciplinarity	0,1%	11,7%	6,2%
IMPACT	**3,4%**	**6,2%**	**4,9%**
Business sense	2,2%	2,5%	2,3%
Social impact	1,0%	3,3%	2,2%
Sustainability	0,3%	0,3%	0,3%
PERSONAL & PROFESSIONAL SKILLS	**16,5%**	**16,5%**	**16,5%**
Self-efficacy	10,1%	8,2%	9,1%
Critical thinking	4,6%	2,7%	3,6%
Self-awareness for professional life	1,8%	5,5%	3,7%
NETWORKING	**2,9%**	**6,4%**	**4,7%**
EXPERIMENTATION & KNOWLEDGE DISCOVERY	**23,9%**	**15,0%**	**19,2%**
Problem solving	6,8%	4,5%	5,6%
Technical solution/Technology	12,0%	6,2%	8,9%
Investigation & Knowledge discovery	2,5%	2,3%	2,4%
Experimentation	2,5%	2,1%	2,3%
SUM	100%	100%	100%
N = Documents	38	39	77

Table 32. PDP and CBI Innovation competences percentages based on the total number of coded segments

It is interesting to note the big differences observed in Figure 54 between PDP and CBI in some innovation competences groups. The one with the biggest difference is Planning and Managing a Project, with 22,2% for PDP and only 3,4% for CBI. On the contrary, in Creativity there is an 18,7% for CBI and 9,2% for PDP. Also, in Leadership & Entrepreneurship there is a 13,4% in favor of CBI vs a 5,8% in PDP. Another important difference is found in Experimentation & Knowledge discovery, with 23,9% in favor of PDP vs 15% in CBI. Teamwork (16,1% PDP vs 20,5 % CBI) and Personal & Professional Skills (16,5% in both PDP and CBI) have less difference.

Finally, even though there are less mentions in general, there is approximately double of them in CBI in Impact (3,4% PDP vs 6,2% CBI) and in Networking (2,9% PDP vs 6,4% CBI).

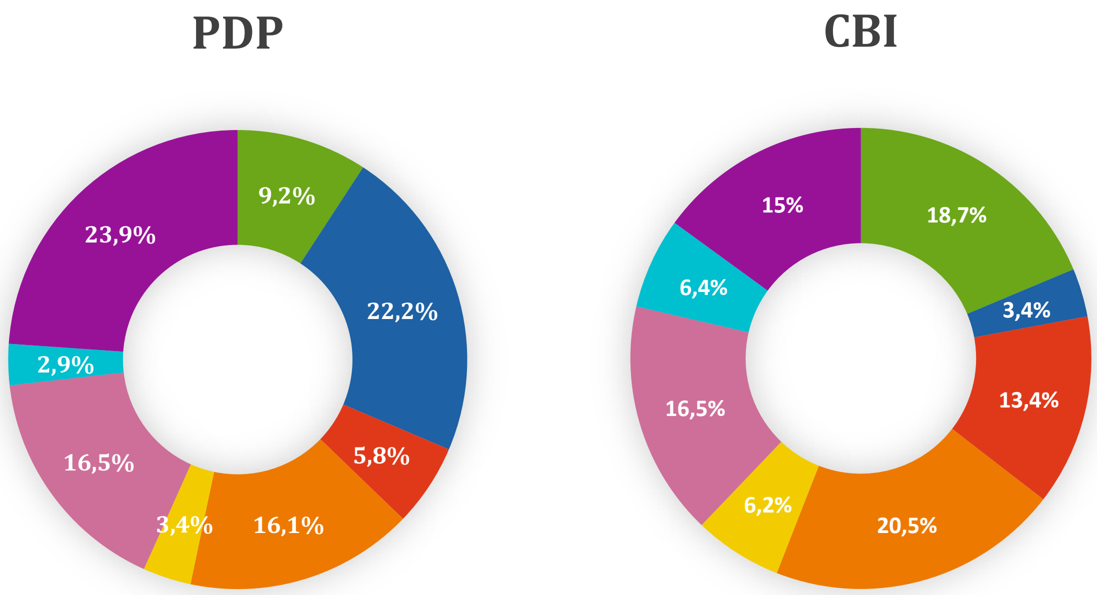


Figure 54. Total PDP and CBI Innovation competences themes percentages based on the total number of coded segments (SUM 100%)

When analyzing the groups of innovation competences or themes, it is observed that both courses CBI and PDP help to develop all innovation competences as shown in Table 33. Nevertheless, each course clearly emphasizes some competences over others as observed in Figure 55 and Figure 56. Planning and Managing a Project (175 in PDP vs 30 in CBI), Leadership & Entrepreneurship (46 in PDP vs 117 in CBI) and Creativity (73 in PDP vs 164 in CBI) are the three groups of innovation competences with the biggest differences. On the other themes/groups of innovation competences the differences are not as big in a general view, but when looking at specific competences (codes) within the themes great differences can be found as observed in Table 32. It is also observed that Experimentation & Knowledge Discovery (320), Teamwork (306) and Personal & Professional Skills (274) are the competences with most coded segments in total.

	PDP		CBI		Total
	Nº of coded segments	%	Nº of coded segments	%	
CREATIVITY	**73**	**22%**	**164**	**78%**	**237**
User awareness	21	36%	37	64%	58
Uncertainty management	47	42%	65	58%	112
Idea generation	5	9%	53	91%	58
Design Thinking	0	0%	9	100%	9
PLANNING AND MANAGING A PROJECT	**175**	**86%**	**30**	**14%**	**205**
Planning	36	97%	1	3%	37
Organization	103	86%	17	14%	120

Time management	36	75%	12	25%	48
LEADERSHIP & ENTREPRENEURSHIP	**46**	**16%**	**117**	**84%**	**163**
Entrepreneurship	0	0%	21	100%	21
Leadership/Initiative	13	21%	50	79%	63
Energy	33	43%	44	57%	77
Risk-propensity	0	0%	2	100%	2
TEAMWORK	**127**	**41%**	**179**	**59%**	**306**
Communication	49	60%	33	40%	82
Coordination	77	64%	44	36%	121
Multidisciplinary	1	1%	102	99%	103
IMPACT	**27**	**35%**	**54**	**65%**	**81**
Business sense	17	44%	22	56%	39
Social impact	8	22%	29	78%	37
Sustainability	2	40%	3	60%	5
PERSONAL & PROFESSIONAL SKILLS	**130**	**45%**	**144**	**55%**	**274**
Self-efficacy	80	53%	72	47%	152
Critical thinking	36	60%	24	40%	60
Self-awareness for professional life	14	23%	48	77%	62
NETWORKING	**23**	**29%**	**56**	**71%**	**79**
EXPERIMENTATION & KNOWLEDGE DISCOVERY	**189**	**56%**	**131**	**44%**	**320**
Problem solving	54	58%	39	42%	93
Technical/Technology development	95	64%	54	36%	149
Investigation & Knowledge discovery	20	50%	20	50%	40
Experimentation	20	53%	18	47%	38
SUM	790	47%	875	53%	1665
N = Documents	38	38 (49%)	39	39 (51%)	77

Table 33. Innovation competences themes total number of coded segments and percentages

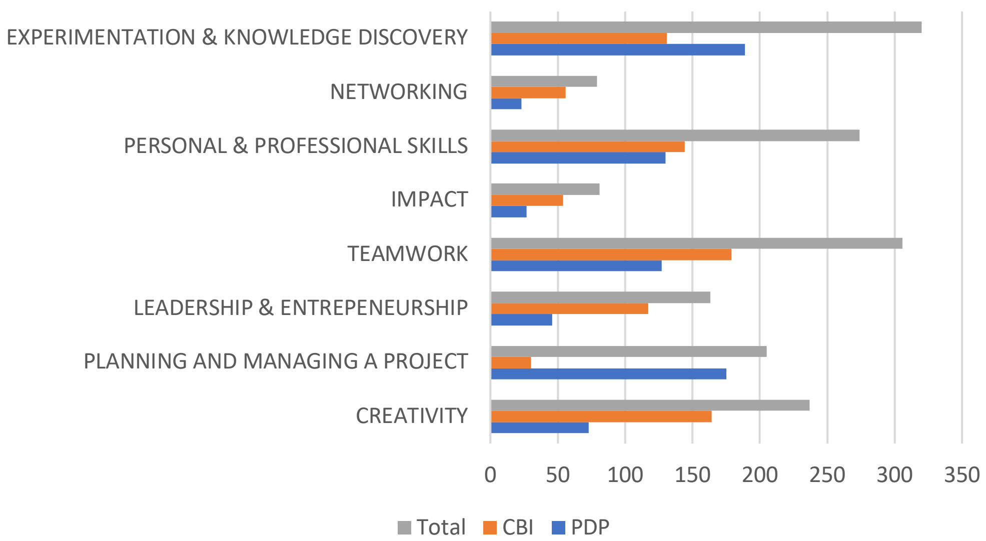


Figure 55. CBI and PDP total coded segments by innovation theme

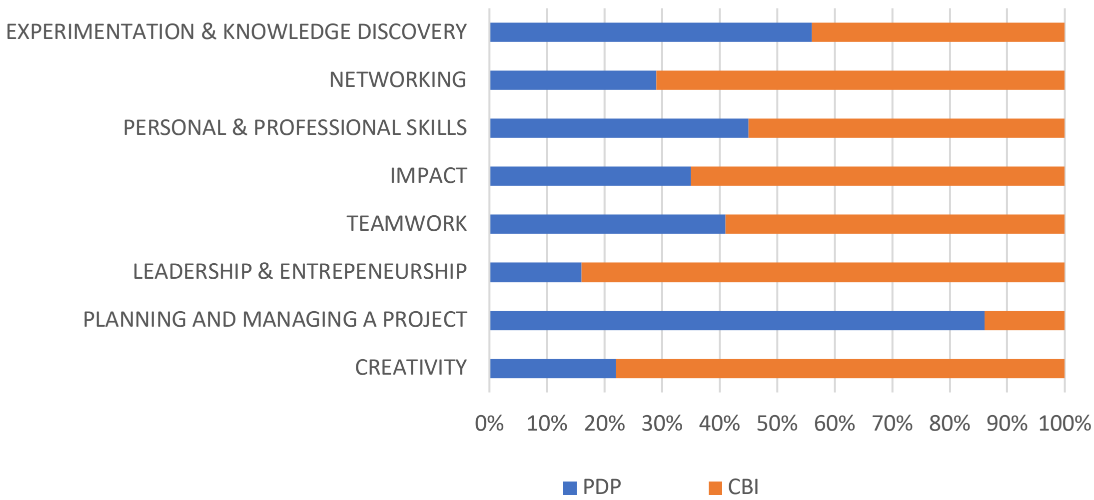


Figure 56. CBI and PDP total innovation themes coded percentages

On a deeper level of detail, as shown in Figure 57, analyzing the percentages of specific innovation competences we can observe big differences in PDP and CBI. While in PDP the bigger percentages of coded segments can be found in Organization (13%), Technical solution/technology (12%), Self-efficacy (10,1%), Coordination (9,7%), Problem Solving (6,8%) and Communication (6,2%); in CBI the bigger percentages are in Multidisciplinarity (11,7%), Self-efficacy (8,2%), Uncertainty management (7,4%), Networking (6,4%), Technical solution/Technology (6,2%) and Idea generation (6,1%).

In general, it could be said that CBI has a more balanced distribution of innovation competences development, while in PDP it is more concentrated towards some specific engineering related competences. The following paragraphs discuss with higher level of detail the results by code categories and display some relevant quotations of the students.

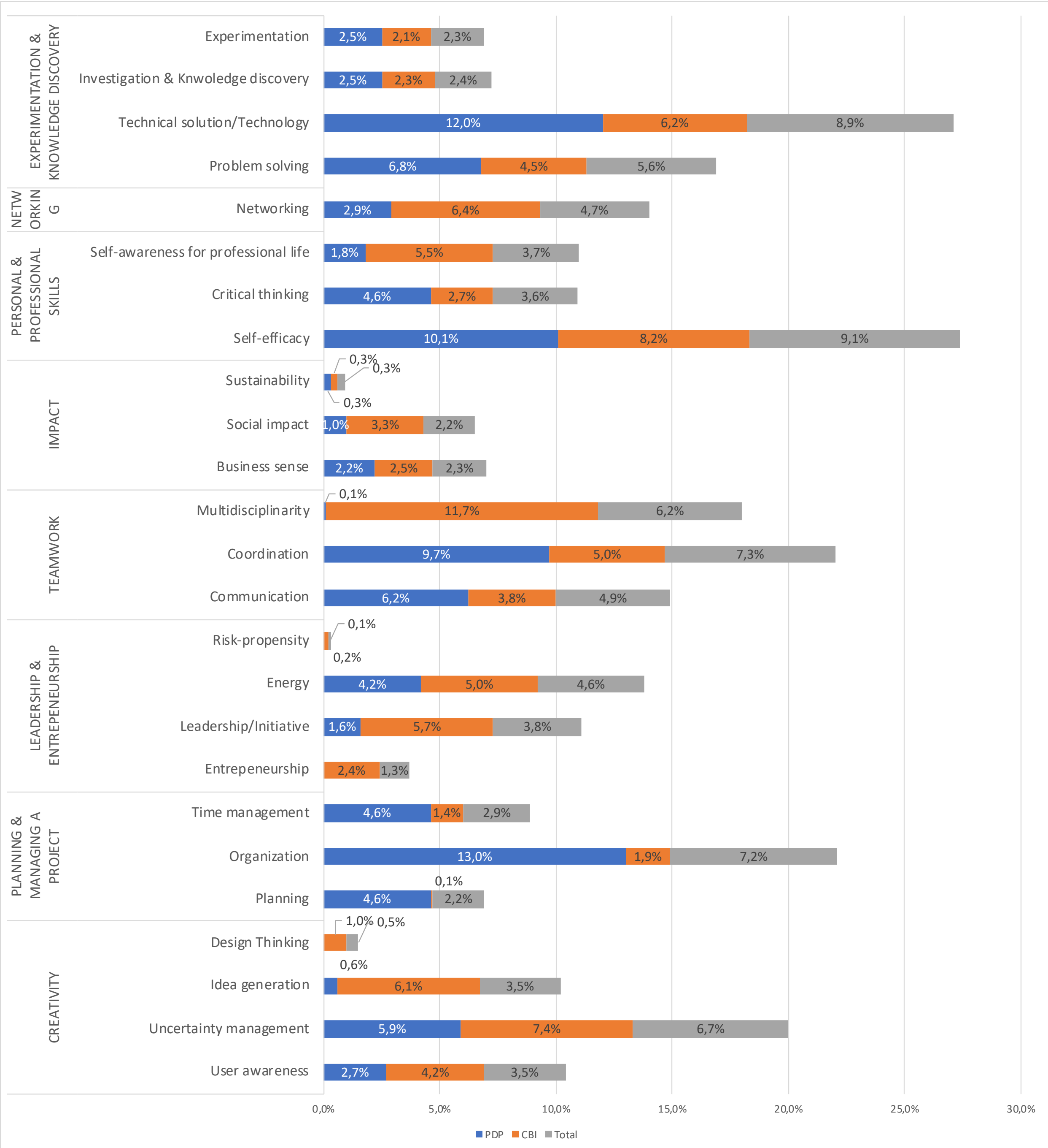


Figure 57. PDP and CBI Innovation competences percentages based on the total number of coded segments

4.1.1. Project Management

The innovation competences related to Planning and Managing a Project (planning, organization & time management) are which in average is found the biggest difference between the two courses. Out of a total of 205 coded segments, 175 are from PDP and 30 are from CBI (86% in PDP vs. 14% in CBI). This is clearly observed in Figure 58 and 59. Within the three competences related to Project Management, the biggest difference found is in Planning, with 36 (97%) mentions in PDP and only 1 (3%) mention in CBI. The differences are big too in Organization, with 103 (86%) in PDP and 17 (14%) in CBI, and in Time Management, with 36 (75%) in PDP and 12 (25%) in CBI.

Some examples of reflections of students related to project management and their learnings are "we did it thanks to good planning and coordination" or "there should be also a more important part in project management, which has proven itself to be the cornerstone of everything, and has been only given a quick look, and it could be an area of interest to some team members, more than the most technical part". Also, more examples of Project Management coded segments are shown in Table 34.

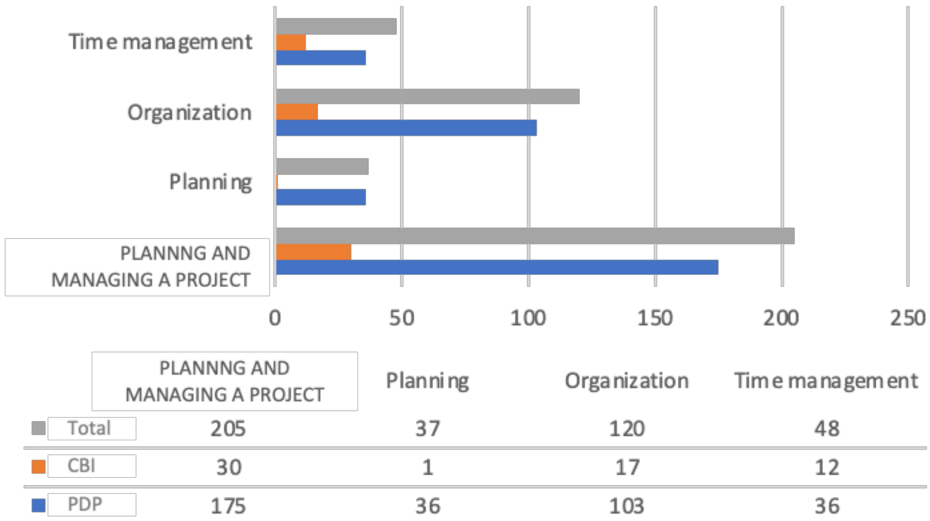


Figure 58. Planning and Managing a Project CBI and PDP number of coded segments

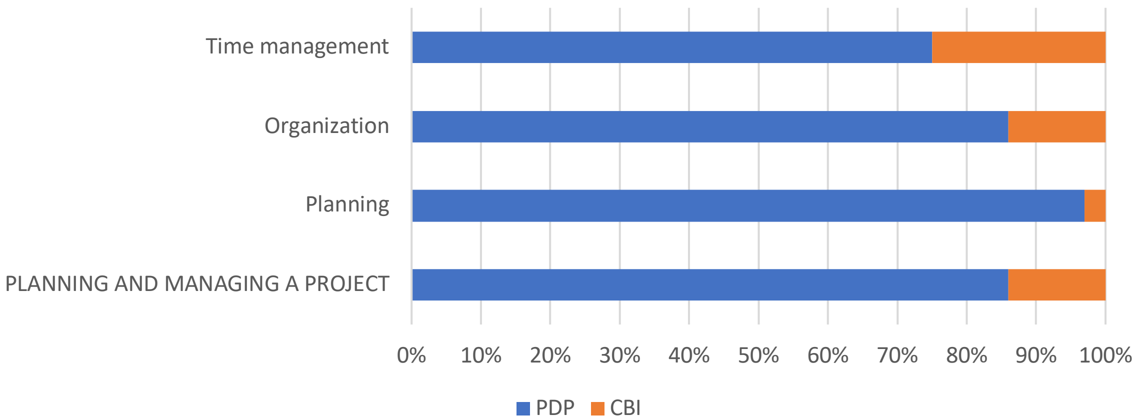


Figure 59. Planning and Managing a Project CBI and PDP coded segments percentage

Innovation competence	**Examples of coded segments**
PROJECT MANAGEMENT\Planning	*We should take into account the importance of a good planning*
	I have learnt project management skills
	The most challenging objective was locating the bottlenecks of the design.
	This is why it is necessary to organize the project from the beginning and define the role of each component.

	After working these months with this project, we can say that we didn't hit the initial planning, since it was unrealistic for the time we had.
	The conditioning subteam did not take into account some design parameters before implementing the chip and this ended up causing an important delay on the whole the project.
	Thanks to the Time Plan we prepared when we started, we worked efficiently and have fulfilled the objectives, meeting every deadline.
	Sometimes it felt like we were planning everything twice.
	Our main difficulty have been the constant planning changes, consequence of poor planning.
	Having a clear idea of the general schema of the project is important
	Perhaps it was due to a poor planning of the tasks resulting from the lack of experience in this field.
PROJECT MANAGEMENT\Organization	*I think this leaded to an unbalanced distribution of tasks, in which engineers ended up with more work than others.*
	I usually coordinated the teammates to meet the deadlines and schedules trying to bring out the best in each team member
	No coordination has been reached at all
	We have been poorly organized and we felt we should have had some coaching to help us with the general organization.
	This is why it is necessary to organize the project from the beginning and define the role of each component.
	I reckon that one of the most essential personal contributions were in the organizational and management tasks.
	The Esade student helped us a lot with the organization and planning and sometimes he took the role of a leader when was useful.
	We have been working in parallel, so we have also enhanced our teamwork.
	It could have been better organized by our team the distribution of work and meeting deadlines regarding the documentation
	Most of those lines respond to organization issues, in a wide sense
	One of them is the organization that we have taken. Surely, we should have organized better.
	The team had learnt the importance of organizing properly
PROJECT MANAGEMENT\Time management	*there wasn't enough time in the course to find out if it is one hundred percent implementable.*
	About the result of the project, I am not completely satisfied, I believe that if we had had more time, our idea would have been clearer.
	take into account many things that we couldn't do in CBI due to time constraints.
	I would have liked to have more time
	What prevented me to push the project on the direction I hoped for was mainly a lack of time.
	It was very stressful because of the lack of time but not difficult. I did the best I could with the technical and time limitations we had.
	We have not usually been able to fulfill the requires tasks in the expected time, although we started with a good pace, the first problems we had, meant big delays due to lack of solutions to them and after them everything was a battle against the clock to complete the project
	The problem was not only the lack of solutions but the execution timing of them, which was neither the optimal one nor a good one.

	Again, time could have been saved having a deep knowledge of these sources, because problems and issues were already reported and solved.
	the project goals and work is really time hungry
	Time was really an issue in this project
	we spent a lot of time advancing in a really slow mode,

Table 34. Planning and Managing a Project CBI and PDP coded segments examples

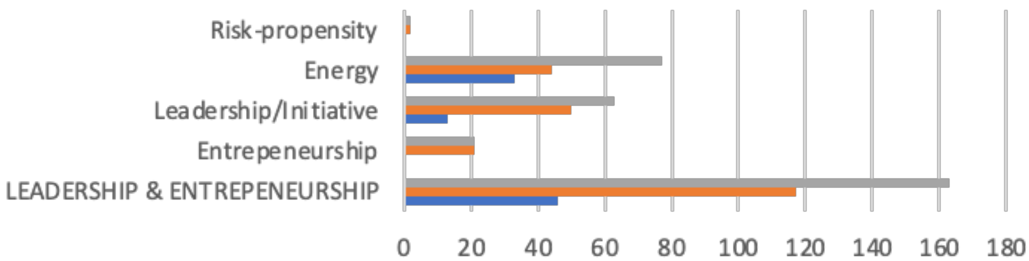
4.1.2. Leadership & Entrepreneurship

Leadership & Entrepreneurship, composed by the competences Entrepreneurship, Leadership/Initiative, Energy and Risk-propensity, is the second set of innovation competences with the major difference observed, being 16% in PDP and 84% in CBI in average. The total number of coded segments is163, with 117 for CBI and 46 for PDP, as observed in Figure 60 and Figure 61. No evidence or mentions of Entrepreneurship are found in PDP and 21 coded segments are found in CBI for this innovation competence.

As examples, some quotes from the students related to entrepreneurship are "Once we continue the research and try a prototype with the costumer we already have, the idea would be to create a startup" or "The role that I would like to play if we create a startup is not only in the technology part, I would like to take part in all the decisions made within the process and also when the company grows"

Regarding Leadership/Initiative, even though that PDP teams are required to define a project leader (while CBI teams don't), there are more findings in CBI related to this competence (50 coded segments in CBI vs. 13 in PDP). As an example, a few quotes from CBI students related to leadership: "I took the lead on organizing what tasks we had to do and who was the responsible of performing those assignments" or "One of the most interesting things I've learned during the course is how to make my voice heard and how to influence team decisions"

Regarding Energy, there is a small difference, with 44 coded segments for CBI (57%) and 33 for PDP (43%). Finally, there are only 2 mentions to Risk-propensity found in CBI. More examples of Leadership & Entrepreneurship coded segments are shown in Table 35.



	LEADERSHIP & ENTREPENEURSHIP	Entrepeneurship	Leadership/Initiative	Energy	Risk-propensity
Total	163	21	63	77	2
CBI	117	21	50	44	2
PDP	46	0	13	33	0

Figure 60. Leadership & Entrepreneurship CBI and PDP number coded segments

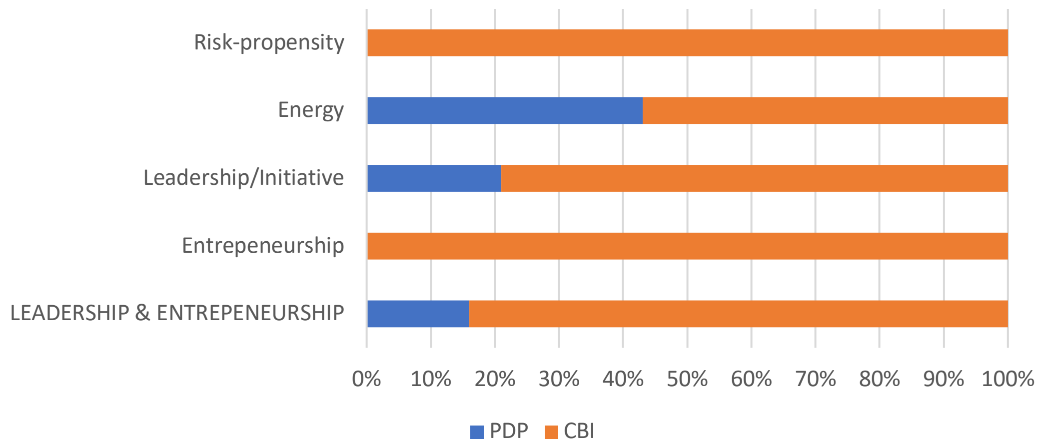


Figure 61. Leadership & Entrepreneurship CBI and PDP coded segments percentage

Innovation competence	**Examples of coded segments**
LEADERSHIP & ENTREPRENEURSHIP\Entrepreneurship	*Once we continue the research and try a prototype with the costumer we already have, the idea would be to create a startup.*
	The role that I would like to play if we create a startup is not only in the technology part, I would like to take part in all the decisions made within the process and also when the company grows.
	My overall opinion right now is that I want to make at least a first fully functional prototype and deliver it to one of the villages in Ghana in order to test it and to turn this "university project" into something real.
	Furthermore, whether it is in this project or in another one, the CBI has opened for me the doors to the entrepreneurship world.
	Before the CBI, I had no idea of how I could begin a startup and now I have at least an idea of which are the initial steps and which are the different ways to get funding.
	We have already contacted a few people, and we are setting interviews in order to increase the visibility of the project and, as a consequence, raise the interest and, eventually, get funding.
	I am more motivated to pursue a career as an entrepreneur
	I would like to remark the experimented entrepreneurship that led me to think in a future developing similar ideas.
	I had never thought about creating a start-up and I envisioned my future working in research, but now I am wondering what to do in my future, since this project has been completely worth and the learning outcomes have been very useful.
	I am a passionate of the entrepreneurial world
LEADERSHIP & ENTREPRENEURSHIP\Leadership/Initiative	*I have been dressed with a leadership role in the team, taking decisions and trying to make the project advance properly. And here I would love to remark that I have been very comfortable in this role.*
	I have always pushed the project in the direction that I hoped.
	I managed to lead the team towards consensus in several situations, and I could see that this is something that not everybody can do.

	I usually coordinated the teammates to meet the deadlines and schedules trying to bring out the best in each team member
	From the very beginning of the project (in the need finding and, what is more important, in the moments where we decided how the group was going to organize and work) I have spoken my mind and exposed my thoughts of what I thought it was better for the team.
	I think I did a good job in expressing my opinions and convincing the rest of the team.
	This project has given me a better understanding of how human relations work, teamwork, that people work in different ways. It's hard to explain all the different outcomes, but now I will feel confident directing a multidisciplinary team in any company.
	I was not commanding what each one has to do, but I was the one who organized and planned the activities and tasks we had to perform.
	I was eager to enhance my managing skills and I succeeded.
	One of the most interesting things I've learned during the course is how to make my voice heard and how to influence team decisions.
	I felt like the group was lacking of a leader and no one seemed to care, so without pretending it I was that figure for many weeks.
	This means that some members could have taken more initiative into the project.
LEADERSHIP & ENTREPRENEURSHIP\Energy	*There has been 4 months of working really hard*
	I still remember that weekend, last Saturday and Sunday of the project, everyone in Geneva having fun, and we in IdeaSquare soldering until 3 midnight... without him it wouldn't have been possible.
	I've loved to work on this project
	the fact that the aim of the project was to provide a solution to reduce youth illiteracy in developing countries was a great incentive
	I have been sometimes the only one working during the week, from Thursday to Thursday, and doing work that I was not supposed to do (more related specifically to the ideation part).
	The environment and the methodology of work were the best and I was motivated all the time
	Thus, we kept ideating, learning about the problem and imagining possible solutions much more time that this was supposed to last. Actually, we kept changing our solution until the last week!
	Right now I feel really excited about the future of this project.
	Indeed we believed (and we still do for sure) in our project, but we could not actually imagine this outcome. This has certainly taught us, on the first place, to aim higher in our expectations and the future of it.
	With all this commitment with minimizing the final price for our product, we worked very hard to achieve it, in order to offer a better and a cheapest way to our clients, who work with minimums with the goal of protecting marine species.
	Factors like time and complexity were crucial during the project, but that didn't stop us from trying
	we enjoyed doing this project and because of that we have putted a lot of effort
LEADERSHIP & ENTREPRENEURSHIP\Risk-propensity	*Because we knew we had our backs we were willing to take more risks and go further away from I initially thought.*
	At the beginning of the course (and also at the end), I felt like if I was continuously going out of the comfort zone.

Table 35. Leadership & Entrepreneurship CBI and PDP coded segments examples

4.1.3. Creativity

Creativity, containing the competences of User awareness, Uncertainty management, Idea generation and Design Thinking, is where is found the third biggest difference of the research, with 22% in PDP and 78% in CBI, from a total number of coded segments of 237 (73 for PDP and 164 for CBI) as shown in Figure 62 and Figure 63.

Within this set of innovation competences, Idea Generation is where the more relevant difference is identified with only 5 mentions in PDP and 53 mentions in CBI. Some examples of quotes from CBI students related to this are "was an interesting experience…to explore different ways of thinking and learning how an idea is created and developed" and also "it is no bad for an engineer to be down to earth but he has to keep in mind his imagination is important too". More examples of Creativity coded segments from both PDP and CBI are shown in Table 36.

Design Thinking has 9 mentions in CBI and no mentions in PDP (it was not explicitly included in this course during the analyzed period).

Even though that PDP is not taking a declared user-centered innovation approach, the difference in the level of user awareness is not as high as in other competences (21mentions in PDP vs. 37 mentions in CBI). As one CBI student mention "we had plenty of interviews with doctors and victims and, for sure, we learnt a lot from them" or "a good engineer does not only have to know about the implementation, he also must think about the real demand of users"

Another big learning in this type of projects is uncertainty management, with little differences found between CBI (47 coded segments) and PDP (65 coded segments). Students struggle in both courses when they don't have an exact specification of what to do. Even though in PDP both requirements and outcomes are more defined, some students mention that "bigger efforts should be put in providing the project with clearer specifications and benchmarks" or "few things could be improved. The first of them is the excessive freedom we are given". Also, a CBI student expressed that "I have the impression we were never told in clear terms what the course was about or what we were expected to do" and "I started to like more and more this methodology although some phases were pushing me outside of my comfort zone".

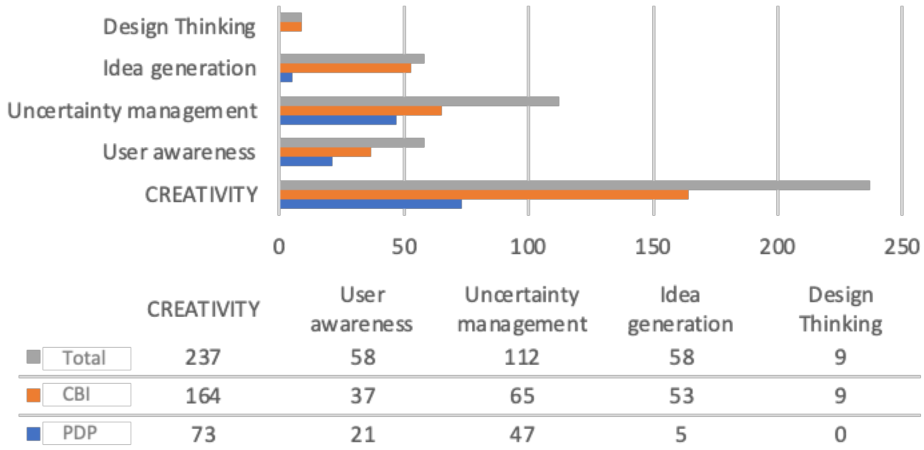


Figure 62. Creativity CBI and PDP number of coded segments

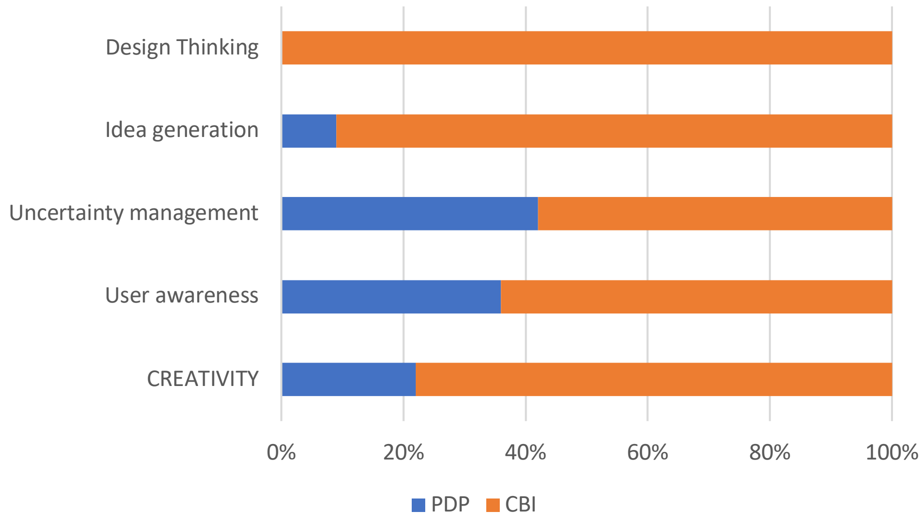


Figure 63. Creativity CBI and PDP coded segments percentage

Innovation competence	Examples of coded segments
CREATIVITY\User awareness	*to study and respond to the user needs*
	We had been trying to develop the most accurate and precise solution for a country that we didn't know, that we hadn't been in, and our objective was to create a solution absolutely adapted for them, thought for them, and to be used by them, and, watching that local people, who know better than no one the problem, really appreciate your solution and find it fabulous is the best feedback I could ever expect.
	accommodation of the product to the harsh conditions at refugee camps,
	We had plenty of interviews with doctors and victims and, for sure, we learnt a lot from them,
	A good lesson was learning how to decide when to act on interviewees opinions. Conducting interviews we started to find contradictions of what people said.
	I would really have like to test final Proton with real users in a comfortable environment and obtain real feedback, and see how much it can help.
	A good engineer does not only have to know about the implementation, he also must think about the real demand of users.

	This part of the project has been changed to fit the necessities the doctors from Sant Joan de Déu asked us for.
	not before establishing the necessities to satisfy
	most of them ideas to tackle some specific problems we had discovered while doing interviews.
	accommodation of the product to the harsh conditions at refugee camps,
	Empathize in specific human needs
CREATIVITY\Uncertainty management	*Despite of that, we think that there are few things that could be improved. The first of them is the excessive freedom we are given.*
	Although we know is a training to what we will find in real life, we found ourselves fighting against a lion with a chair and whip
	Problems proliferated when speaking of CDR (Critical Design Review), since there was no template and it was quite difficult to know what information and how should have been it written.
	This project was not a guided one, we have faced a complete challenge
	bigger efforts should be put in providing the project with clearer specifications and benchmarks.
	On the other hand, I have the impression we were never told in clear terms what the course was about or what we were expected to do.
	I was not sure about my role in the whole project because I thought I would only be useful at the final part when the solution had to be implemented
	Personally, I have felt alone many times during these 3 months.
	we had a wide scenario with many different problems and not that many possible solutions.
	For first time, I was not given the problem in order to solve it, I had to find the problem to then be able to solve it instead.
	As an engineer until the end I didn't feel that I had a very defined role, during the first 2 thirds of the process (diving by visits to CERN) I felt like all the other teammates had their roles much more defined, we as engineers didn't.
	learning to deal with a lot of uncertainty
	Another thing worth mentioning is that I felt much more confident than I expected in coping with uncertainty.
	The first 2 months I felt a little bit useless (like all the team), because we did work, but we did not have a concrete goal, so it was sometimes confusing and not motivating.
CREATIVITY\Idea generation	*Another thing that I would like to highlight is that I had an important role in the idea generation, from my point of view the challenge of my group was quite difficult, so I am really proud that I have been able to contribute that much*
	I now value much more the work done by designers because they have an extreme creativity which is something that it is almost impossible to learn.
	During the first 2.5 months all the team members had no role, just "ideators" it was just in the last weeks when we stared been engineers/MBAs/…
	I think I brought the realistic part when the ideas were going too far, too imaginative.
	I think we all could contribute with some great ideas,
	learning how an idea is "created" and developed
	The research and ideation part seemed a little too long while working on them. However, taking it into perspective, I realized that those parts are the critical ones and they need to be done super accurate in order to obtain good results.

	What I liked most was having the opportunity to bring new ideas to my team and that they were listened
	thinking out of the box
	helping other to develop further their ideas, proposing some more
	New information makes possible new ideas
CREATIVITY\Design Thinking	*I would like to remark the fact that I certainly liked the approach proposed by design thinking process*
	I realized the importance of the design thinking in projects like this one, so I tried to adapt myself into this project, working in other fields like ideation, design, creativity, business, innovation and others.
	After applying the design thinking methodology I can now see the importance of really know and understand the challenge, who are the stakeholders or what will the solution provide in order to end up with a useful and worthy solution.
	I have also learnt about concepts that I knew very little before, such as design thinking, innovation or prototyping.
	Design Thinking activities wasn't helping us a lot.
	I believe that I have learnt the most in the stages when there was no technical part, since, in engineering, I had never gone through a design thinking process.
	Since all the projects that I worked on during the degree were specifically technical projects, working in a multidisciplinary team and applying design thinking was such a big challenge.
	I learned about the design thinking process, which is something I knew nothing about before we started the course, but that finally got to understand

Table 36. Creativity CBI and PDP coded segments examples

4.1.4. Impact

Innovation competences' learning related to impact (Business sense, Social impact and Sustainability) are also having a relevant difference between PDP (35%) vs. CBI (65%), out of a total number of mentions of 81, with 54 for CBI and 17 for PDP as observed in Figure 64 and Figure 65. Even though it is worth mentioning that the total number of mentions related to Impact is not so big (81). The main difference is in Social Impact with 29 mentions in CBI vs 8 mentions in PDP. Regarding sustainability there are only 3 mentions in CBI and 2 mentions in PDP. And regarding business sense, there are 39 mentions, with a little difference in favor of CBI (22) vs PDP (17).

Some examples of what students' highlight is "Explaining how our engineering impacts over society and over the environment is something that always will be demanded by any entity" or "We had the opportunity to verify that our knowledge and our ideas can have a positive impact in the world". More coded segments examples related to Impact can be found in Table 37.

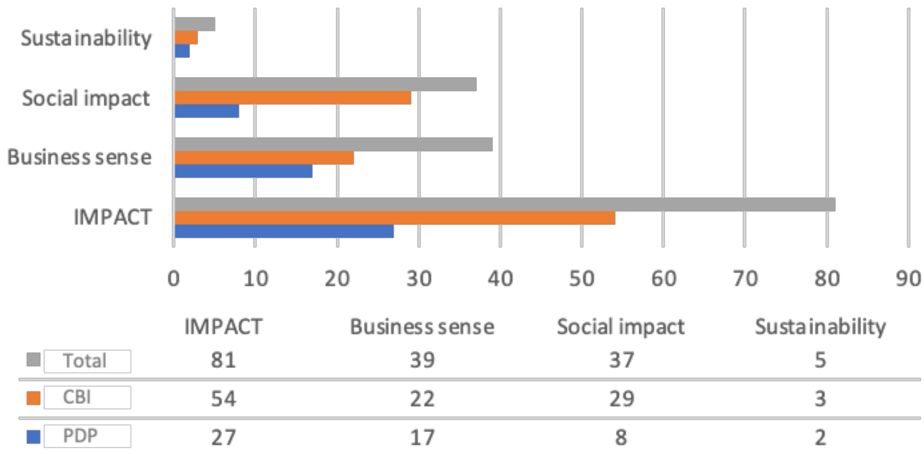


Figure 64. Impact CBI and PDP number of coded segments

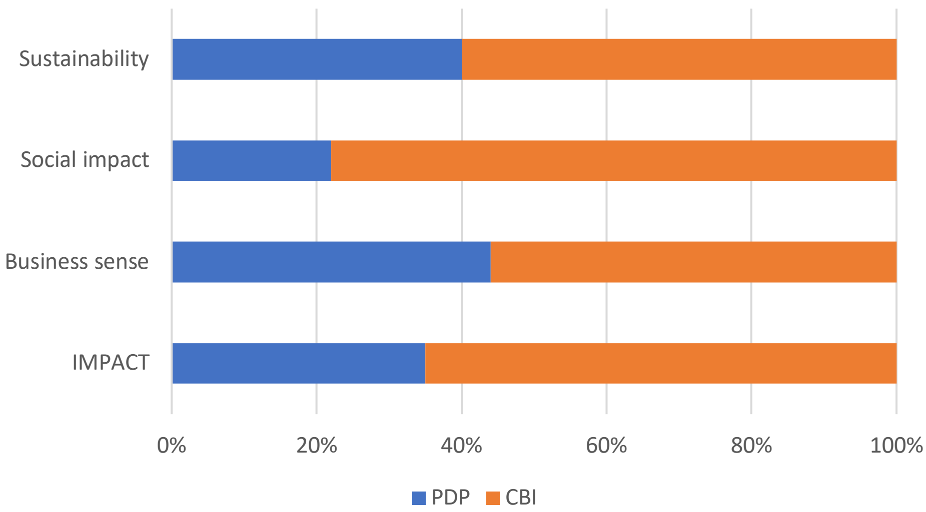


Figure 65. Impact CBI and PDP coded segments percentage

Innovation competence	**Examples of coded segments**
IMPACT\Business sense	*a comprehensive vision on how to develop a project and provide the tools to turn the work into a technological product with demand and that can last.*
	As it's a more NGO style project, the economical part is tough even if we have designed a sustainable business model.
	In my opinion, if we have this huge opportunity of going to the fair, we could receive more feedback and perhaps funding to pursue further the idea. If not, it is going to be difficult to continue working on the project because, personally, I have serious doubts about the financial viability of it.
	will we have investors interested in the idea?
	now I understand a little more about business
	we would need lots of experts, but financially is very difficult
	I wish that we could have got more feedback about the "feasibility" of our project and how interesting it is for someone to invest on it.
	In the business part we have found out something quite interesting, probably the reason of this project, and it is that it could be economically profitable, we could make money from it thanks to relatively low costs and the average high

	price our market niche has. So our efforts could be monetized somehow, or at least it could be tried.
	Taking into account that our client is an ONG and that their members are working in order to protect and preserve the natural environment, they do not have much economical resources.
	From what real life aspects is concerned, understanding what net salary and gross salary are is an important point to take into account in planification. Also, that they are less than the total amount paid by the company. How taxes and deductions affect your salary it is also an important point.
IMPACT\Social impact	*The most important one is related to privacy and the amount of information we are giving for free to the net without realizing it. All this information can be used by people who knows how the network works and then use it in a variety of ways, which can have good or bad intentions. We know there are some privacy laws concerning this case, but they may not be sufficient to guarantee our network privacy.*
	A thought in the design phase can make a difference. It is too easy to forget about how small actions such a sending an e-mail can impact over the world. That is why we, as engineers, have to keep in mind how our products and services use resources and end their useful life.
	We are proud of the project we have built up and we expect it will be improved so it will finally be used by doctors in real life and be useful for these medical workers and general users that work in underdeveloped countries or in the countryside to help decrease the deaths of pneumonia of the risk groups of population (kids under 5 years and adults over 65 years old) all around the world.
	being a social project that aims to help people with huge needs is the best part of it. I love that this could have a great impact on society and that it could help a lot of people.
	We had the opportunity to verify that our knowledge and our ideas can have a positive impact in the world.
	I think the project has a real potential for being further developed and, eventually, reach the field and have an impact on people's life.
	As an engineer, I obviously expect to become an active part of the development of a product that can actually help thousands of people.
	I believe we had a very powerful idea that could make a difference in our society
IMPACT\Sustainability	*It also has raised awareness about SDGs in myself and people close to me.*
	we reached a solution for developed countries that was beneficial for the environment.
	The fact that they are oriented towards a more sustainable world gives them even more hype.
	Explaining how our engineering impacts over society and over the environment is something that always will be demanded by any entity.
	features like the costs or the sustainability

Table 37. Impact CBI and PDP coded segments examples

4.1.5. Networking

The total number of evidences found in the analyzed documents related to networking is small (79) compared to other themes as shown in Figure 66 and Figure 67. It has more weight in CBI (71%) than in PDP (29%). In most cases related to contacts with stakeholders and companies, as mentioned by one student "regarding the companies we met during the course, we are analyzing which of them are the best so as to purpose a partnership". Also, more examples of coded segments related to Networking can be found in Table 38.

One thing to highlight is the relationship with CERN in CBI, which is mentioned a total of 17 times in the 39 CBI personal reflections & project conclusions with examples like "working with such a good institution as CERN has made us build a very powerful contact network".

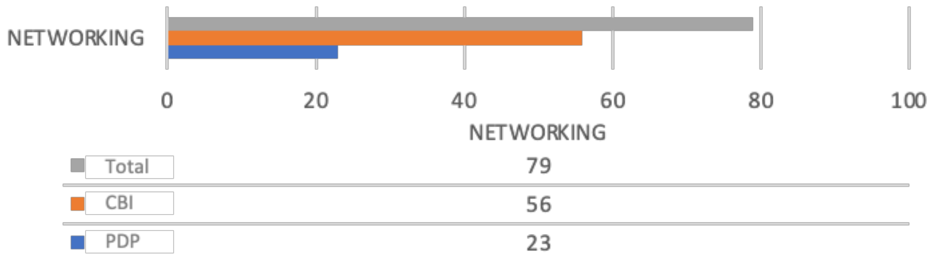


Figure 66. Networking CBI and PDP number coded segments

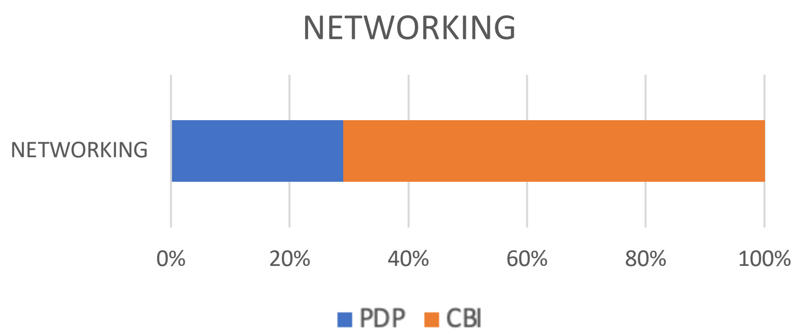


Figure 67. Networking CBI and PDP coded segments percentage

Innovation competence	Examples of coded segments
NETWORKING	*Unfortunately, for the case of my team, CERN did not play any significant role. We could have obtained all of the collected information from other sources.*
	I don't know if we will need anything or not but having their contact and knowing them personally we can feel safe that we could have their support in case we needed it.
	From the C2MON team at CERN, we receive an invitation to participate in a contest organized by Software AG to showcase our project at the CeBIT 2016. We have spoken with them and they have told us that they love the idea and that after the holidays we will talk further to discuss what will be in the showcase of the exhibition.
	how to contact and treat interesting people for the project
	We have already contacted a few people, and we are setting interviews in order to increase the visibility of the project and, as a consequence, raise the interest and, eventually, get funding.
	Since we have the contact details of the coachers, we are planning to contact them in the near future so as to receive specific help. Moreover, we have contacts in CERN that kindly offered us support.
	Regarding the companies we met during the course, we are analysing which of them are the best so as to purpose a partnership or at least to receive some feedback to improve our approach.

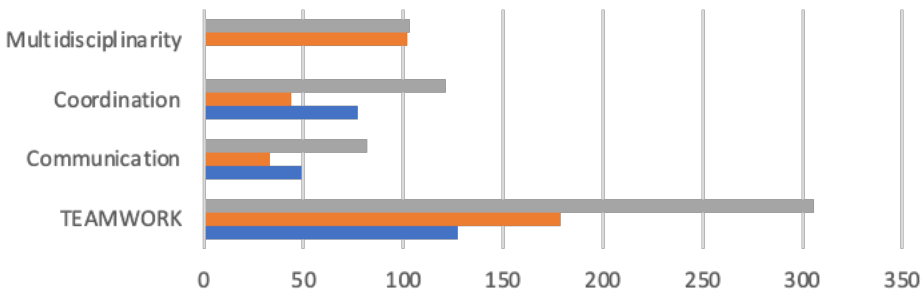
	The way I envision the future of this project is being sponsored by one or more global institutions such as UNESCO, UNHCR, CERN, etc.
	making contacts and relations with all kind of people that could be useful in the future.
	Connect with people we would never have imagined exchanging more than one word with them.
	we have learnt how to work for a big company such as HP.
	We are happy with the result of our work, and we think that both UPC and Accenture as well.

Table 38. Networking CBI and PDP coded segments examples

4.1.6. Teamwork

As observed in Figure 68 and Figure 69, overall, there is a small difference between PDP (41%) and CBI (59%) students' competences development within Teamwork (Communication, Coordination and Multidisciplinary) with a total number of coded segments of 306 (127 for PDP and 179 for CBI). Specific mentions to coordination and communication are found with little more frequency in PDP students' analyzed documents (49 vs 33 for Communication and 77 vs 44 for Coordination) with examples like "we could have done better as a team is to communicate more often and more accurately between the different subgroups", "the team's weakness during the project was organization".

Nevertheless, the big difference is in the multidisciplinary competence. In CBI students' documents there are found 102 mentions to this competence, being the most mentioned topic by this course students. In PDP there is only 1 mention, and even it refers to multidisciplinary it is actually considering different engineering specialties. The fact that in CBI the teams are composed by students of three different institutions and different profiles (engineering, business and design) is highly appreciated by engineering students, as observed in the documents. They mention things like "the fact of working with people from other disciplines gave me an insight of the real world that I couldn't have received from any other place" or "before doing this project I thought that other disciplines were not as useful as my own. Now I can see that the part of engineering needs all the other disciplines as much as they need us in the process of building a company". More examples of Teamwork coded segments can be found in Table 39.



	TEAMWORK	Communication	Coordination	Multidisciplinarity
Total	306	82	121	103
CBI	179	33	44	102
PDP	127	49	77	1

Figure 68. Teamwork CBI and PDP coded segments

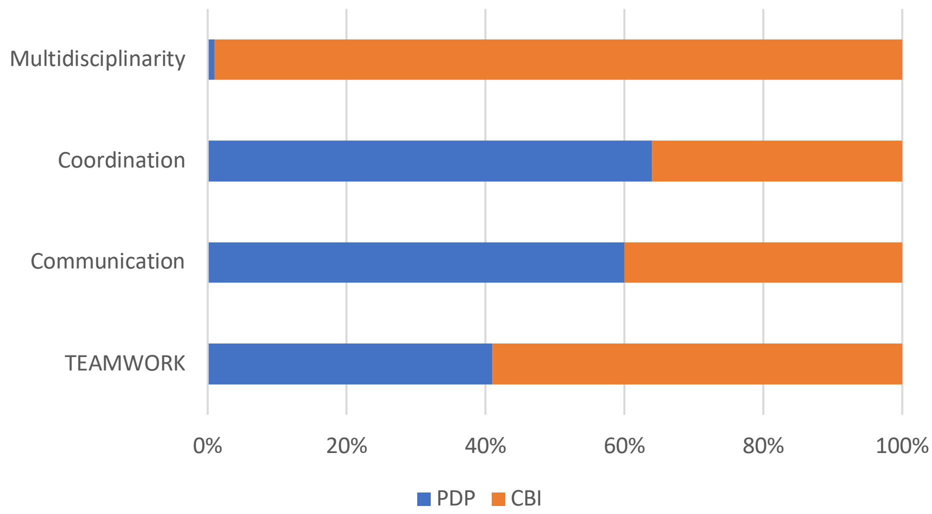


Figure 69. Teamwork CBI and PDP coded segments percentages

Innovation competence	Examples of coded segments
TEAMWORK\Communication	*The main communication of the team has been in the PAE classes, but a constant communication via WhatsApp of the management team has been very important to organize the tasks every week.*
	we should also take into account the good communication between the group. Thanks to the weekly meetings, all the group was kept well informed. This point needs special remarks considering that the team was composed by a large number of people.
	One of the things we could have been done better as a team is to communicate more often and more accurately between the different subgroups. We worked pretty good individually or in pairs, but this lack of communication has made us difficult to merge the work of the different groups. If we had communicated better, we would all start the work from the same point and we could avoid these problems.
	the constant communication with the client via slack as well as the meetings we did during the project has been really useful to have feedback on the product while in development.
	I also have had the opportunity in the project to lose my fear to speak in public thanks to the numerous times we had to present.
	The communication between teams regarding the final integration was sometimes a little bit confusing.
	lots of presentations, which was very helpful to improve communication skills.
	I have more power in communication.
	In this project I realized that I am good at talking to people and understanding other points of view
	I have learnt a lot about team structures and how important is communication inside a team.
TEAMWORK\Coordination	*However, we had difficulties when coordinating because there was no time devoted for working together within course schedule, save for days at CERN. We had lectures on different days, so teamwork was not facilitated.*
	No coordination has been reached at all, and the final performance has been much better than I personally expected when I was working on the project. There have been unilateral decisions whenever a member on the team wanted, no consulting to the other team members, poor quality work and work done without any research.
	in the team, we collaborated really well between us.
	We have been working in parallel, so we have also enhanced our teamwork.

	We have also been outstanding in the interpretations of the other teams needs, i.e. if someone had a vision of how our product could be implemented, or some new features that could be added, everyone thought how could, his/her team, help in that new idea and how could that be developed.
	good work atmosphere and coordination among the different work subgroups.
	A way of solving this problem is to assign tasks from different blocks to each group, so that every component of the team understands completely how the system is being implemented.
	Also, some people redistribution could have been done to get the work finished earlier or better taking into account that some team members have not spent as much time as others.
	As more dedicated roles were distributed, the team members have had more defined jobs.
	The overall team performance was positive.
	Coordination among members of the team is something crucial in order to assign and perform the different tasks of the project in order to ensure that tasks that are performed by the different members are in sintony.
	this was solved and an improvement in our teamwork was seen
TEAMWORK\Multidisciplinarity	*to work in teams with diverse composition*
	As the teams were multidisciplinary, this project was a big change from all the other projects I have been doing since I started University.
	I think that the fact of working with people from other disciplines gave me an insight of the real world that I couldn't have received from any other place. So I find that being able to do this project was really valuable.
	About the fact of the multidisciplinary teams I have to add that, before doing this project I thought that other disciplines were not as useful as my own. Now I can see that the part of engineering needs all the other disciplines as much as they need us in the process of building a company.
	Being able to listen to business and design people when they explain their own part-solution has taught me a lot of methodologies and concepts from those areas
	The experience has given the opportunity to have a first approach to the professional world where multi-disciplinary teams are the most common reality.
	The three constituent parts of the project (business, design and engineering) have allowed to examine the different dimensions that any project should include.
	Working with our designer has been the worst and most difficult experience I have ever had during my courses. Maybe I am very far from their point of view, but I have seen on other groups amazing work done by the designers.
	how to treat with people who has not the same background as you in the team
	My role inside the group was as an engineer but I had the chance to implement my role and learn from the others.
	During CBI I've realised how tricky is to work in a multidisciplinary team and the differences in the way of thinking of the different professionals. I've learned to deal with very different people and to always search for a middle point where everyone agreed and felt involved.
	I have realized diversity can only sum up, and teaches you that anybody can contribute to any aspect of the project, no matter his or her expertise.
	One of the learnings I need to highlight from this multidisciplinary team working is the following: "The most important thing an engineer can add to a multidisciplinary team is not technical knowledge but a unique way of facing problems."
	My key takeaway of this project is clearly how much a team can improve by incorporating multidisciplinary.

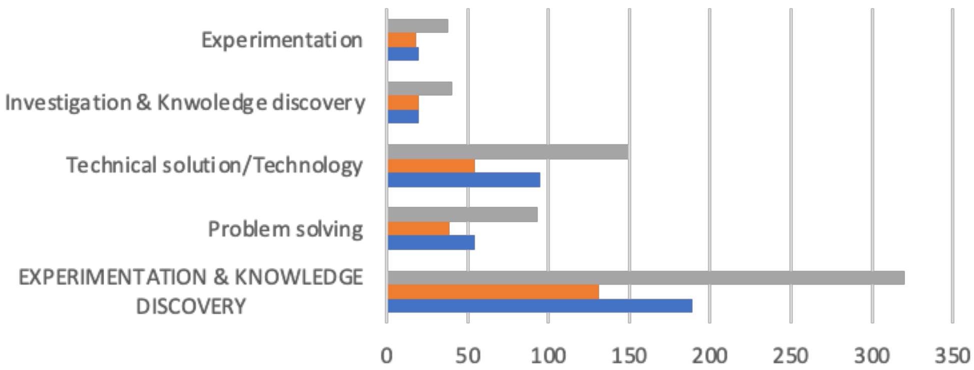
	I learned how to work with professionals of different backgrounds and I realized that I am really good as the join of techies and business.

Table 39. Teamwork CBI and PDP coded segments examples

4.1.7. Experimentation & knowledge discovery

Within Experimentation & Knowledge Discovery competences (Problem solving, Technical/Technology development, Investigation & Knowledge discovery and Experimentation) the difference found between PDP and CBI is 64% vs. 36% out of a total of 320 coded segments, with 189 for PDP and 131 for CBI as observed in Figure 70 and Figure 71. Problem solving (54 in PDP vs 39 in CBI), Investigation & Knowledge discovery (20 in both PDP and CBI) and Experimentation (20 in PDP and 18 in CBI) are pretty well balanced in both courses as found in the analysis of projects' documentation and reports. The main difference is the fact that in PDP there is more evidence of mentions related to Technical/Technology development, being 64% (95) vs 36% (54) in CBI of a total of 149.

Examples of quotes like "using Blockchain Technology we have successfully tackled the royalty distribution problem", "a complete architecture for the radar has been built and a display for monitoring the vital signs has been designed, which also include the heartbeat frequency, breath rate and alarms in case of tachycardia, bradycardia and apnea" or "we have seen that one way to do an accurate design is to have a simple prototype that works and then to improve it". More examples of coded segments of Experimentation & Knowledge Discovery can be found in Table 40.



	EXPERIMENTATION & KNOWLEDGE DISCOVERY	Problem solving	Technical solution/Technology	Investigation & Knwoledge discovery	Experimentation
Total	320	93	149	40	38
CBI	131	39	54	20	18
PDP	189	54	95	20	20

Figure 70. Experimentation & Knowledge Discovery CBI and PDP coded segments

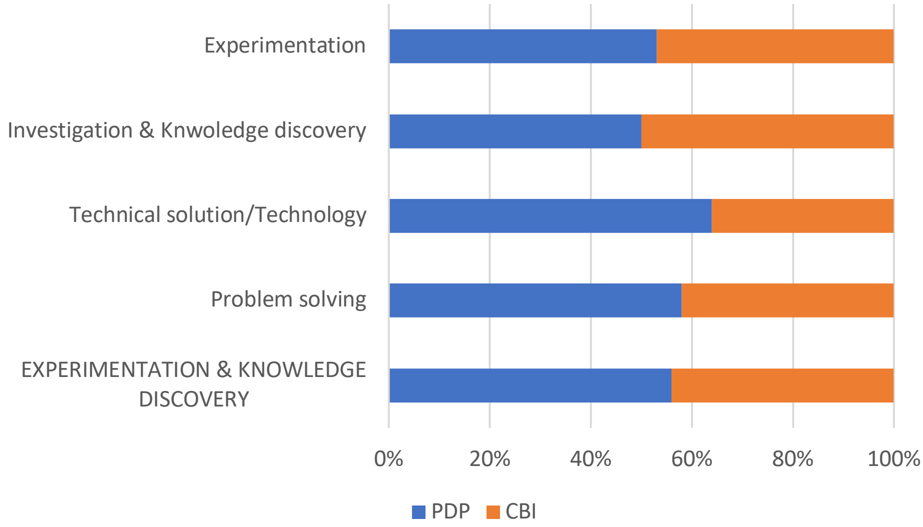


Figure 71. Experimentation & Knowledge Discovery CBI and PDP coded segments percentages

Innovation competence	Examples of coded segments
EXPERIMENTATION & KNOWLEDGE DISCOVERY\Problem solving	*results proved to fix this matter in some way*
	We looked for the smallest and cheapest electronic components, in proportion. Also, we looked for a battery that offers the power that we need without costing us a fortune. We found a way to make pressure studies in a very cheap way, as well as researching to find the low cost mechanical materials that we need.
	Firstly, the main objective of the project is to detect and track the respiration of a baby and his heartbeat, and it can be considered as achieved.
	Regarding the first statement we have succeed on reducing driver's distractions by implementing a robust hand gesture recognition system with leap motion. It is fast enough to recognize the gesture made by the driver, this way the hand has to be away from the steering wheel a very short period of time instead of the large period of time the driver faced when looking for buttons and not paying enough attention to the road.
	Using Blockchain Technology we have successfully tackled the royalty distribution problem.
	Symmetra is a new way of communication that lets people transmit information more clearly by interacting with virtual objects and projecting those interactions to reality.
	I think we came up with an accurate analysis of the issues and problems in education, and we envisioned solutions in the right direction.
	I am enthusiastic because the output of the project is a solid idea that can be implemented and it can solve an existent problem.
	I am really happy that both engineers in Team Carson, have achieved all the requirements of the conceptual product and successfully solved all the troubles that we found
EXPERIMENTATION & KNOWLEDGE DISCOVERY\Technical solution/Technology	*have learnt a lot of computer vision and C++ programming*
	The concept could be interesting, but some technical issues have to be solved, like the light source that could provide UV and infrared radiation.
	Arnau (computer science) took charge of the blockchain (software) and I (telecom) was in charge of the fingerprint sensor (hardware).
	As for the technical part, I'm happy to have read so much about blockchain, one of the trending technologies nowadays. I'm also satisfied of having learned how to build a basic website and server in a few days

	Perhaps I expected a little more focus on technical skills, but I've enjoyed it anyway.
	my initial expectations were that it was going to be a more technological project and we did not have enough time to design and develop our prototype and focus on the technical part.
	My project has made me learn the basics about biomedical-oriented IoT
	In the data modelling part we found out that, as explained before, there was a deviation in the measures value due to the way we carried out the measure, squatting instead of lying on a horizontal position and despite of that we also realized that this deviation was corrected thanks to the impedance the dry electrodes added to the system.
	We have also realized that the bioimpedance technology is a pretty good tool to track health parameters, giving accurate measures if they are carried out in the expected positions, but it has a major downside, it has to be always under the same conditions, and never while practicing sport because otherwise, it has a lot of variability
	The microprocessor code works but is not optimized to achieve the best performance, this is a task that could be improved if we had a little more time.
	Additionally, we have been able to find all the components of digital type. This has allowed us to obtain a final product with very simplified electronics that make us expect a higher reliability compared to other tags in the market.
	Not even the programming languages (C++ or Yaml) are studied at the University, only a simpler language ("C").
EXPERIMENTATION & KNOWLEDGE DISCOVERY\Investigation & Knwoledge discovery	*First of all we started doing a little market research to analyze what kind of product What could we make, to meet the specifications.*
	A lot of time on the beginning was invested researching, gathering information and getting some knowledge basis to start to work with.
	the team has learned to never underestimate previous work or the primary sources of information
	After all the research and work done during the duration of the project we have come to some important conclusions about MAC Randomization.
	Doing a deep research about the subject we were treating was fundamental.
	finding and contrasting information was difficult.
	I learnt a lot about the way of gathering information about one topic
	in order to build our prototypes, I had to do a huge research and learn by my own.
	Investigation is just as important as interviewing, interviews only work if you know what you know what you are talking about.
	one must expect that the outcome of the project could be completely different from the initial thoughts, because this is about using the tools to build, but also, and more importantly, to discover.
	I think we managed to define well our assumptions and know where our biggest knowledge gaps were
	The research part was the worst for me. I am not used to doing research on these topics at all and more in our case because it was more difficult since we were focusing on Africa. But, I did my best to learn about how to write emails, make good interviews, etc.
EXPERIMENTATION & KNOWLEDGE DISCOVERY\Experimentation	*I want to make at least a first fully functional prototype and deliver it to one of the villages in Ghana in order to test it*
	Then, I started to do engineering so that we could have the prototype: I had no idea about VR but with some effort, I could do the prototype work nicely after those 2 weeks at CERN.
	I would really have like to test final Proton with real users in a comfortable environment and obtain real feedback, and see how much it can help.

	I would have liked very much to be able to have a functional prototype to be able to iterate over and over our solution, test it with real users and improve it.
	I believe it strongly depends on the prototyping being carried out by every team, and I believe that that freedom makes the project better.
	testing comes as a milestone.
	One clear example of this discussion is the Karma Attack, which even though we did some tests and verified that it could be possible to do it (not feasible), we concluded it could be used to attempt to people's privacy in a way that one could monitor all their sent data to the network, which is some development we would not like to contribute.
	We have seen that one way to do an accurate design is to have a simple prototype that works and then to improve it.
	we have explored different ways to approach the problem and learned from each of them.
	we studied others possibilities, like use a band that reduce the clouds (microwave band)
	In particular, we learned a lot about the Agile methodology and how the Developing-Testing iteration works
	In this project five different methods were tested. As explained before, we have 3 different prototypes for hardware, MATLAB scripts as a support and a way to gather relevant results to improve hardware prototypes, and the deep neural network, which gave us the best expectations at the beginning and the best results at the end.

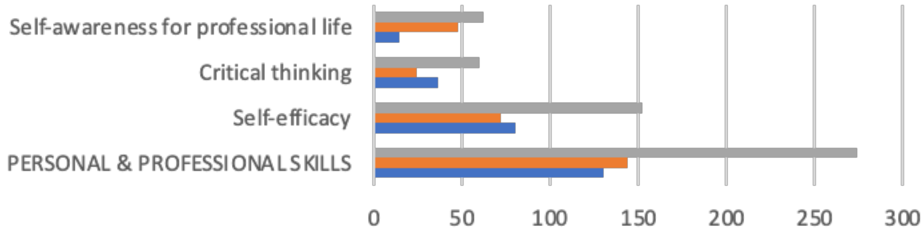
Table 40. Experimentation & Knowledge Discovery CBI and PDP coded segments examples

4.1.8. Personal & professional skills

Regarding Personal and professional skills (Self-efficacy, Critical Thinking and self-awareness for professional life), there is a very slight difference found in favor of CBI (55%) respect to PDP (45%), with a total of 274 coded segments (130 for PDP and 144 for CBI) as shown in Figure 72 and Figure 73.

Competences related to Critical thinking (36 for PDP vs 24 for CBI) and Self-efficacy (80 for PDP vs 72 for CBI) are found with little differences in both courses' students analyzed documents, with a little more emphasis on PDP students. Some quotes related to these topics are "I have learnt many things here that any theoretical course or lecture can't teach, and I feel much more prepared now for the real life, real projects and real work."

What makes the difference in this group is the competence defined as Self-awareness for professional life, which is more mentioned in CBI (77%) than in PDP (23%). This refers to what students mention as "this project has taught me a lot of key skills that are crucial for the professional life", "we have learnt a lot from other branches which are in principle not taught in engineering and that surely they are essential in the professional world", "I have learned a plethora of things that I am sure will be very valuable for my future professional career" and "the learning outcomes of the project are both very valuable and very sought in the professional world". More examples of Personal & Professional coded segments can be found in Table 41.



	PERSONAL & PROFESSIONAL SKILLS	Self-efficacy	Critical thinking	Self-awareness for professional life
Total	274	152	60	62
CBI	144	72	24	48
PDP	130	80	36	14

Figure 72. Personal & Professional Skills CBI and PDP coded segments

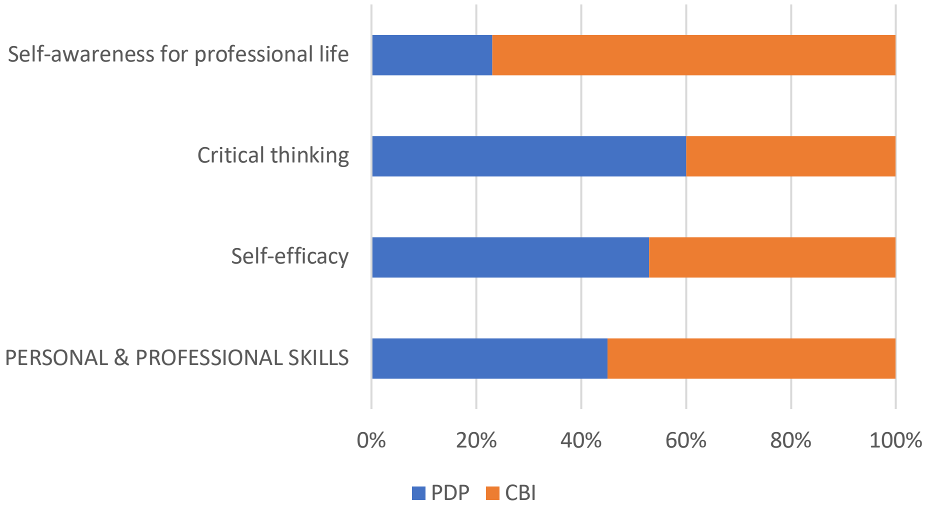


Figure 73. Personal & Professional Skills CBI and PDP coded segments percentages

Innovation competence	**Examples of coded segments**
PERSONAL & PROFESSIONAL SKILLS\Self-efficacy	*we have seen that we have the knowledge to do many things*
	this project has wide-opened our eyes, giving us a much broader perspective of our field of study
	although we could think we were not able to do some things, we have acquired skills that have allowed us to face big problems and solve them step by step and in little and easier pieces
	we can state we have achieved the overall goal of the project.
	The first and the most important in this project is that we could create a new product
	we might not be the bigger experts in neural networks but we have managed to develop a product from basically scratch
	we believe that the learning outcomes have brought us great value as engineers
	I think that my piece has been key in the team.

	I have always felt very relevant in the team, I have always noticed a lot of support and confidence on me and that has been fundamental during the development of the whole project.
	if you propose something to yourself, you are capable of developing amazing solutions and coming up with great ideas.
PERSONAL & PROFESSIONAL SKILLS\Critical thinking	*In my opinion, engineering side has been really disregarded for the whole course – I would be fine with that if so was stated from the beginning, so that students who would apply for this subject could know what they would actually find, but this has not been the case.*
	I had a role of not losing the reality of what is feasible and what is not, being a little bit critical with the ideas that the other team members had. Sometimes, this role may be a little bit annoying for the rest of the group members, but from my point of view, it is totally necessary if the final output has to be implemented.
	About the result of the project, I am not completely satisfied.
	I think I can do good analysis at a system level and I have often played the role of the devil asking lots of questions and making sure we were not missing anything.
	from my point of view the proposed solution was not the best
	I don't think it's innovative enough to dedicate so much time.
	despite all the hard work of all of us, we didn't reach the final objective.
	The RADAR still has a lot of room for improvement.
PERSONAL & PROFESSIONAL SKILLS\Self-awareness for professional life	*Controller structure of the project, a very common skeleton project that we will definitely encounter in the many projects we may participate in the future.*
	On a personal level we have gained a very valuable experience from working on a real-world challenge.
	this project has taught me a lot of key skills that are crucial for the professional life.
	The experience has given the opportunity to have a first approach to the professional world where multi-disciplinary teams are the most common reality
	This period has also been an opportunity to know myself on a deeper level and further develop relationship and professional skills
	it was an enriching experience that made me learn lots of things of real-life projects that I probably would not learned at university.
	I have learnt many things here that any theoretical course or lecture can teach, and I feel much more prepared now for the real life, real projects and real work.
	I think this course is a fantastic approach to the real-life situations that we may have to confront in a few years.
	The experience I have had during the CBI course has been very satisfactory: I have learned a plethora of things that I am sure will be very valuable for my future professional career.
	CBI course experience has been very valuable for me, as I have been able to learn a lot of things that I could not have learned by doing a normal university course.
	I will define this project as a complete once-in-a-lifetime and valuable experience
	the influence of both organizers and lecturers was intentionally minimized (as it was possible) to allow the students develop the engineering skills of working in an organized enterprise as well as soft-skills like team cooperation and expression of self as an active, aware of his/her function in a group part of a functional "engineering organism".
	the project was a great opportunity for the students to evolve in a domain that they did not have an opportunity before and develop skills that are desired in contemporary engineering environment.

	We have to value a lot this knowledge and take profit of it when we go into the world of work.
	other important thing to value is the experience we have taken with a big business like Banc Sabadell. It's very different the university life than dealing with a big business. Here we have seen how they work and the dynamic of bringing a project of this dimensions, so if we are another time into a situation like this, we will know how we have to behave. Therefore, the experience of become into a big project is the other thing that we take.

Table 41. Personal & Professional Skills CBI and PDP coded segments examples

Another analysis made is the visual representation of the coded documents', obtained from the software used MAXQDA, where it is observed the weight of the codes in the analyzed documents. These are called Document Portraits. The software transforms the coded segments of the analyzed tests into a visual representation comprised of a standarized number of points colored according to the code system color code (Figure 74).

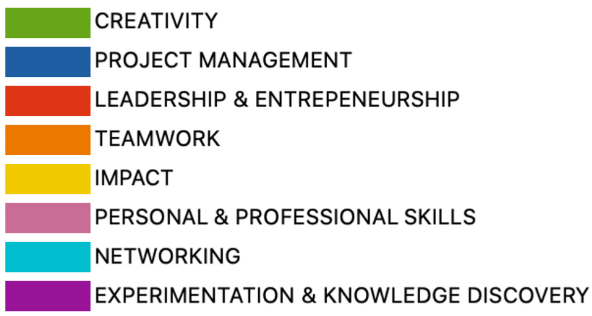


Figure 74 – Code system colors

When comparing the documents portraits of PDP vs. the document portraits of CBI, it is visually observed the weight/frequency of each code according to the color system. For example, in CBI document portraits (Figure 75) it is observed a bigger amount of orange which is the color of TEAMWORK and mixed other colors, while in PDP (Figure 76) it is observed a bigger amount of violet, the color of EXPERIMENTATION & KNOWLEDGE DISCOVERY. It is worth to note that these document portraits do not show the overlapping of codes. Many coded segments are coded with more than one code. This is not represented in the document portraits.

Figure 75. CBI Document portraits / color coding weight

Figure 76. PDP Document portraits / color coding weight

Another interesting aspect to analyze is the word frequency in the documents, which can be visualized in word clouds (Figure 77 and Figure 78).

Irrelevant words like connectors and prepositions were eliminated and not taken into account. In Table 42 and Table 43, we can observe the list of the first 50 most frequent words in the analyzed documents for CBI and PDP. We can see the frequency (how many times the word appears) and in how many documents and in which percentage of documents the word can be found.

Notably, the first three words are the same for both courses, and in the same order: *project*, *work* and *team*. In the case of CBI, these three words appear in all (100%) analyzed documents. On the contrary, in PDP, the word *project* appears in 97% of analyzed documents and the word *team* does it in 84% of them. Even these three words are the top three mentioned words in both courses, there are slight differences. In PDP, the word *project* has a frequency of 362 (3,29%) while in CBI it is 324 (3,09%). Also, the word *work* has a higher frequency in PDP, 252 (2,29%) vs. 232 (2,21 %) in CBI. The third word, *team* has a higher frequency in CBI (210-2%) than in PDP (193-1,76%).

In CBI, the fourth frequent word is *think* appearing in 92% of the documents with a frequency of 196 (1,87%). Notably, in PDP the word *think* is in position number 23, appearing in 61% of the documents, with a frequency of 44 (0,40%). The fourth word in PDP it is *time*, that is found in 89% of the documents with a frequency of 141 (1,28%). The word *time* is found in position 8th in CBI, with a frequency of 77 (0,74%) in 74% of the documents. It is interesting to note that while in CBI the fifth word in frequency is *idea* (196-1,87%), to find the word *idea* in PDP we need to go to position number 46 in frequency (29-0,26%). The fifth word in PDP is *learn* with a frequency of 83 (0,75%). This word is in position number 6 in CBI, although with a higher frequency (112-1,07%).

The next group of words in the top 10 of CBI are *people, time, cbi* and *experience*, while in PDP are *result, system, problem, member* and *document*.

CBI					
Nº	Word	Frequency	%	Nº Documents	Documents %
1	project	324	3,09	39	100
2	work	232	2,21	39	100
3	team	210	2,00	39	100
4	think	196	1,87	36	92
5	idea	112	1,07	31	79
6	learn	112	1,07	37	95
7	people	100	0,95	34	87
8	time	77	0,74	29	74
9	cbi	71	0,68	31	79
10	experience	71	0,68	31	79
11	engineer	70	0,67	29	74
12	take	67	0,64	27	69
13	technical	67	0,64	25	64
14	problem	65	0,62	28	72
15	solution	63	0,60	25	64
16	help	59	0,56	27	69
17	able	58	0,55	25	64
18	feel	58	0,55	19	49
19	future	57	0,54	31	79
20	good	56	0,53	24	62
21	little	56	0,53	24	62
22	know	55	0,53	26	67
23	group	53	0,51	26	67
24	cern	51	0,49	26	67
25	interest	49	0,47	24	62
26	member	49	0,47	21	54
27	process	49	0,47	23	59
28	role	49	0,47	25	64
29	need	45	0,43	25	64
30	challenge	44	0,42	19	49
31	design	44	0,42	23	59
32	go	44	0,42	25	64

PDP					
Nº	Word	Frequency	%	Nº Documents	Documents %
1	project	362	3,29	37	97
2	work	252	2,29	38	100
3	team	193	1,76	32	84
4	time	141	1,28	34	89
5	learn	83	0,75	30	79
6	result	72	0,65	29	76
7	system	72	0,65	27	71
8	problem	72	0,65	23	61
9	member	68	0,62	25	66
10	document	67	0,61	35	92
11	group	66	0,60	26	68
12	task	65	0,59	23	61
13	achieve	59	0,54	30	79
14	take	53	0,48	24	63
15	conclusion	50	0,45	37	97
16	design	50	0,45	18	47
17	use	50	0,45	18	47
18	good	49	0,45	26	68
19	help	49	0,45	25	66
20	communication	48	0,44	23	61
21	product	48	0,44	22	58
22	new	47	0,43	21	55
23	think	44	0,40	23	61
24	improve	44	0,40	20	53
25	test	44	0,40	20	53
26	know	43	0,39	22	58
27	implement	40	0,36	16	42
28	come	39	0,35	17	45
29	development	37	0,34	17	45
30	able	36	0,33	20	53
31	give	36	0,33	20	53

33	see	43	0,41	24	62
34	get	42	0,40	23	59
35	give	42	0,40	21	54
36	prototype	42	0,40	22	56
37	much	39	0,37	23	59
38	try	39	0,37	22	56
39	you	39	0,37	18	46
40	continue	38	0,36	21	54
41	find	38	0,36	20	51
42	just	38	0,36	17	44
43	start	37	0,35	20	51
44	contribute	35	0,33	19	49
45	real	35	0,33	18	46
46	opinion	34	0,32	21	54
47	out	34	0,32	21	54
48	say	34	0,32	23	59
49	always	33	0,32	13	33
50	aspect	33	0,32	21	54

Table 42. CBI word frequency

32	little	35	0,32	25	66
33	start	34	0,31	20	53
34	people	34	0,31	15	39
35	plan	34	0,31	14	37
36	need	33	0,30	20	53
37	objective	33	0,30	20	53
38	goal	30	0,27	19	50
39	develop	30	0,27	17	45
40	go	30	0,27	17	45
41	lack	30	0,27	17	45
42	get	30	0,27	16	42
43	image	30	0,27	8	21
44	change	29	0,26	18	47
45	process	29	0,26	18	47
46	idea	29	0,26	15	39
47	find	29	0,26	12	32
48	information	29	0,26	12	32
49	whole	28	0,25	17	45
50	finish	28	0,25	16	42

Table 43. PDP word frequency

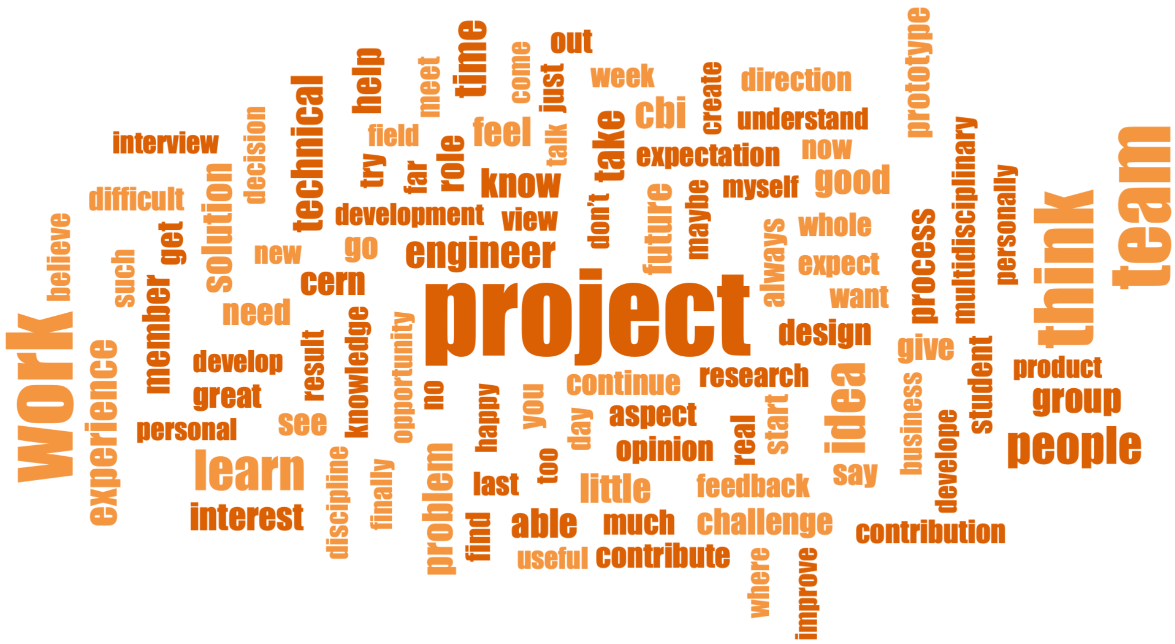


Figure 77. CBI word cloud based on word frequency

Figure 78. PDP word cloud based on word frequency

4.2. Results of the quantitative research: Self-perception

Regarding the responses to the INCODE Barometer Rubric 5, in a scale of 0 to 5, we got answers in the whole range from 1 to 5 (the complete list of answers is available in the Annex of this thesis). All answers' averages were in the high segment of the scale, in the range 3,59 to 4,56 for CBI and 3,45 to 4,57 for PDP. Figure 79 shows the means of the answers for the 25 questions of the INCODE – Rubric 5 for both groups.

Figure 79. INCODE Rubric 5 – Innovation competences self-perception results CBI vs. PDP courses

Comparing the aggregated answers of the three dimensions and the overall set of answers (Table 44), the total average score of CBI is 4,09 and for PDP is 4,03. The difference between the two means is only 0,06 representing only a 1,5% in favor of CBI (p=0.06) as can be observed in Table 44.

	CBI (n 32)			**PDP** (n49)							
Dimension	**n**	**mean**	**SE**	**n**	**mean**	**SE**	**Mean diff**	**%**	**Hyp**	**p**	**Validation**
Individual	384	4,10	0,04	588	3,92	0,04	0,19	4,6%	>	0,0002	✓
Interpersonal	256	4,04	0,05	392	4,09	0,04	-0,06	-1,5%	<	0,1990	×
Networking	160	4,11	0,08	245	4,18	0,06	-0,07	-1,7%	<	0,2280	×
Aggregated	800	4,09	0,03	1225	4,03	0,03	0,06	1,5%	>	0,0620	~

Table 44. INCODE Rubric 5 – Dimensions Aggregated Results CBI vs. PDP.
Mean differences (absolute and relative %) and one-sided null-hypothesis p-values and rejection validation using the following significance level thresholds and symbols: Null-hypothesis rejected ✓: $p \leq 0{,}05$; marginally rejected ~: $0{,}05 < p < 0{,}2$; non-rejected ×: $p > 0{,}2$

Regarding the aggregated answers by dimensions, there are also similar results but with a bigger difference for the Individual dimension. It performs significatively better in CBI (mean difference of 0.19, 4.6%, p=0.0002). The Interpersonal and Networking dimensions perform slightly better in PDP, but the difference is not significative (p in the range of 0.2 in both cases). Figure 80 displays the mean and its 95% confidence interval for each dimension and for the aggregated answers.

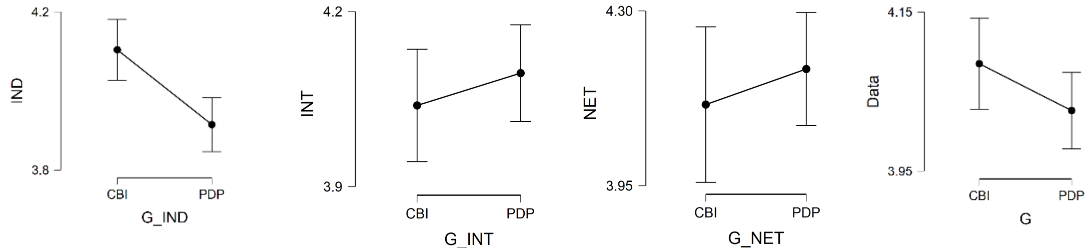


Figure 80. INCODE Rubric 5 – Aggregated Results CBI vs. PDP. For the 3 dimensions and the whole set of answers. Group means and 95% confidence intervals

When looking at the specific competences, the ones with the bigger differences (5% or more) belong mostly to the Individual competences dimension. Table 45 displays the means, standard errors, differences among means and p-values of the 12 competences of the individual dimension, and Figure 81 displays the mean and its 95% confidence interval for the survey answers corresponding to each competence.

		CBI (n=32)		**PDP** (n=49)						
#	**Individual competences**	**mean**	**SE**	**mean**	**SE**	**Mean diff**	**%**	**Hyp**	**p**	**Validation**
1	I present ideas that are suitable for the task	4,31	0,11	4,12	0,10	0,19	4,4%	>	0,1040	~
2	I present creative ideas	3,75	0,15	3,86	0,12	-0,11	-2,9%	<	0,2890	×
3	I present new ways to implement ideas	4,13	0,13	3,82	0,12	0,31	7,5%	>	0,0500	✓
4	I evaluate the advantages and disadvantages of actions	4,53	0,10	4,08	0,11	0,45	9,9%	>	0,0030	✓
5	I identify relationships among different components of the task	4,16	0,14	3,92	0,12	0,24	5,7%	>	0,1040	~
6	I face the task from different points of view	4,09	0,14	4,00	0,12	0,09	2,3%	>	0,3080	×
7	I use available resources ingeniously	3,94	0,16	3,63	0,15	0,31	7,7%	>	0,0870	~
8	I foresee how events will develop	3,72	0,12	3,69	0,11	0,02	0,7%	>	0,4410	×
9	I show enthusiasm	4,09	0,15	4,16	0,11	-0,07	-1,7%	<	0,3500	×
10	I persistently pursue the goals	4,41	0,11	4,12	0,10	0,28	6,4%	>	0,0360	✓
11	I take daring yet reasonable risks	3,91	0,12	3,45	0,13	0,46	11,7%	>	0,0100	✓
12	I orient the task towards the target	4,22	0,12	4,12	0,11	0,10	2,3%	>	0,2780	×

Table 45. INCODE Rubric 5 Individual Competences Results, CBI vs. PDP.
Mean differences (absolute and relative %) and one-sided null-hypothesis p-values and rejection validation using the following significance level thresholds and symbols: Null-hypothesis rejected ✓: $p \leq 0{,}05$; marginally rejected ~: $0{,}05 < p < 0{,}2$; non-rejected ×: $p > 0{,}2$

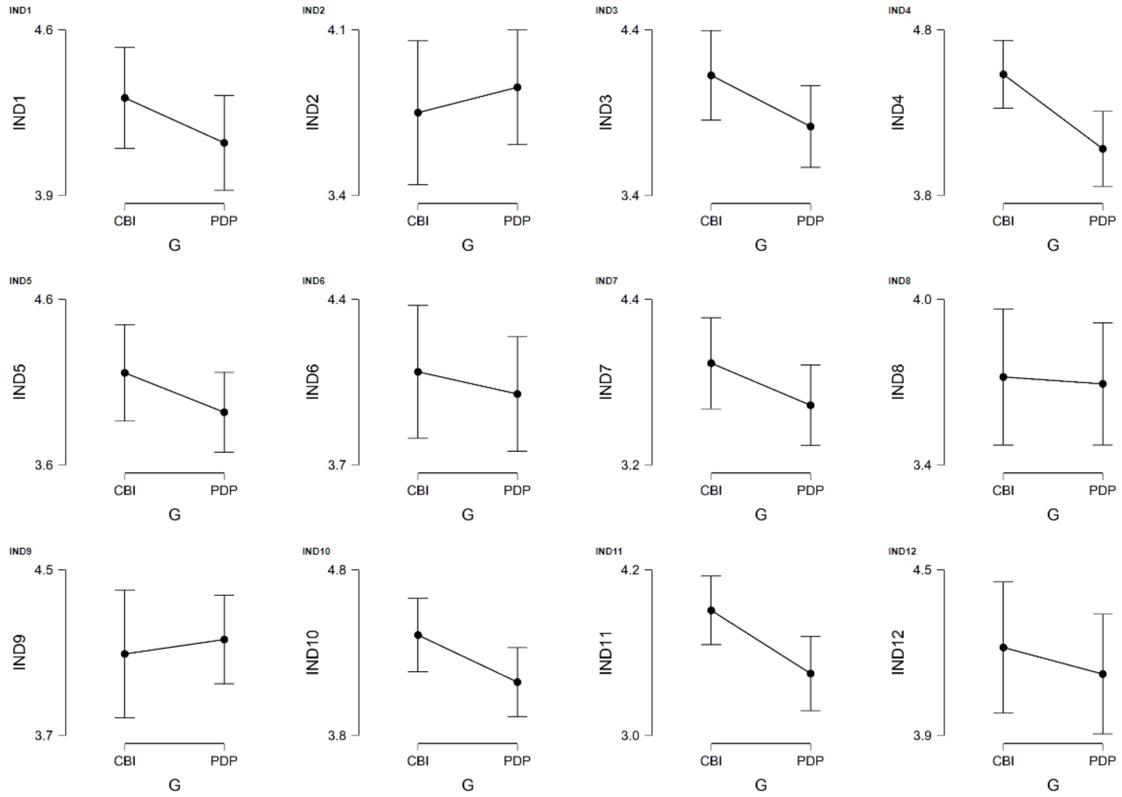


Figure 81. Individual Competences Results, CBI vs. PDP. Group means and 95% confidence intervals

The competences with mean differences bigger than 5% and statistically significative ($p \leq 0.05$) are number 3, 4, 10 and 11. They will be commented in the discussion section. Competences 1, 5 and 7 have non-negligible differences, near 5% but the difference is marginally significative ($0.1 \leq p \leq 0.05$) because of the higher dispersion in the answers. All the other competences give small and non-significative differences, including the only one which gives a slightly better result for PDP than for CBI in this individual dimension, competence 9.

In the Interpersonal competences dimension (Table 46 and Figure 82), they display small and non-significative differences ($p>0.1$) with both positive and negative signs. Only one (competence 18, I take initiatives) gives a p value in the border of 0.1 with a positive difference of 4,9% towards CBI.

		CBI (n=32)		**PDP** (n=49)						
#	**Interpersonal competences**	**mean**	**SE**	**mean**	**SE**	**Mean diff**	**%**	**Hyp**	**p**	**Validation**
13	I transmit ideas effectively	3,59	0,14	3,80	0,12	-0,20	-5,6%	<	0,1370	×
14	I listen to teammates	4,34	0,13	4,43	0,12	-0,09	-2,0%	<	0,3250	×
15	I establish constructive group relationships through dialogue	4,03	0,12	4,22	0,12	-0,19	-4,8%	<	0,1380	×
16	I collaborate actively	4,13	0,15	4,29	0,11	-0,16	-3,9%	<	0,1960	×
17	I contribute to group functioning	4,25	0,12	4,25	0,10	0,00	0,1%	>	0,4870	×
18	I take initiatives	4,25	0,12	4,04	0,11	0,21	4,9%	>	0,1050	~
19	I drive others to act	3,78	0,13	3,71	0,13	0,07	1,8%	>	0,3650	×
20	I face conflicts with flexibility to reach agreements	3,94	0,15	4,02	0,10	-0,08	-2,1%	<	0,3190	×

Table 46. Interpersonal Competences Results, CBI vs. PDP.

Mean differences (absolute and relative %) and one-sided null-hypothesis p-values and rejection validation using the following significance level thresholds and symbols: Null-hypothesis rejected ✓: p ≤ 0,05; marginally rejected ~: 0,05 < p < 0,2; non-rejected ×: p > 0,2

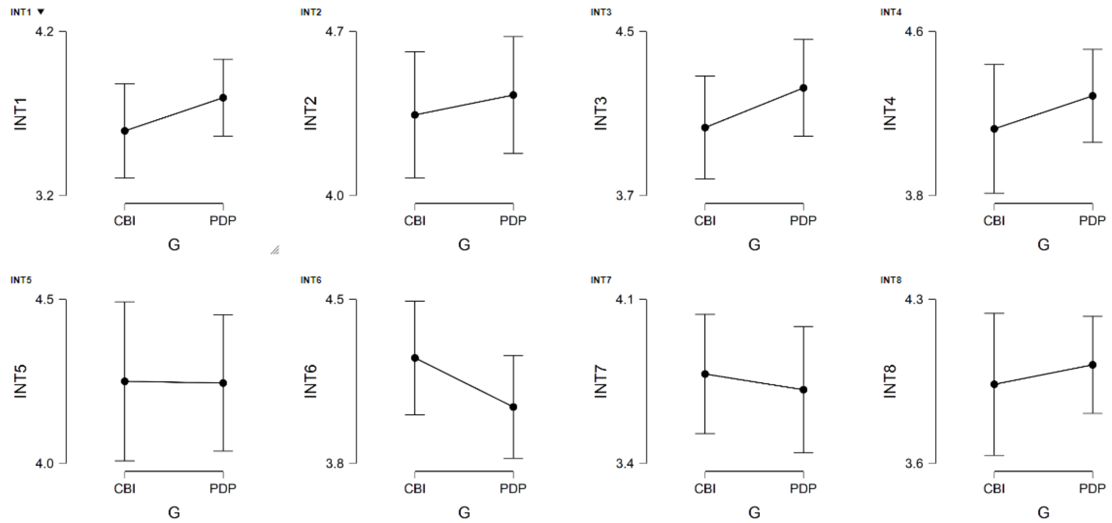


Figure 82. Interpersonal Competences Results, CBI vs. PDP. Group means and 95% confidence intervals. Labels INT1 to INT8 correspond to skills of the Interpersonal dimension (13 to 20).

Finally, in the Networking Competences (Table 47 and Figure 83) the differences among means are also small and with high p-values, with the only exception of competence 21 (I apply ethical values) which gives a difference towards PDP of 7,1% with p=0.083, the only negative difference moderately significative.

		CBI (n=32)		**PDP** (n=49)						
#	**Networking competences**	**mean**	**SE**	**mean**	**SE**	**Mean diff**	**%**	**Hyp**	**p**	**Validation**
21	I apply ethical values	4,00	0,17	4,29	0,12	-0,29	-7,1%	<	0,0830	~
22	I take into account the implications of the task for society	3,88	0,19	3,88	0,15	0,00	-0,1%	<	0,4960	×
23	I am able to work in multidisciplinary environments	4,53	0,09	4,39	0,10	0,14	3,2%	>	0,1610	×
24	I am able to work in multicultural environments	4,56	0,09	4,57	0,09	-0,01	-0,2%	<	0,4730	×
25	I use networking contacts to reach goals	3,59	0,23	3,80	0,14	-0,20	-5,6%	<	0,2150	×

Table 47. Networking Competences Results, CBI vs. PDP.

Mean differences (absolute and relative %) and one-sided null-hypothesis p-values and rejection validation using the following significance level thresholds and symbols: Null-hypothesis rejected ✓: p ≤ 0,05; marginally rejected ~: 0,05 < p < 0,2; non-rejected ×: p > 0,2

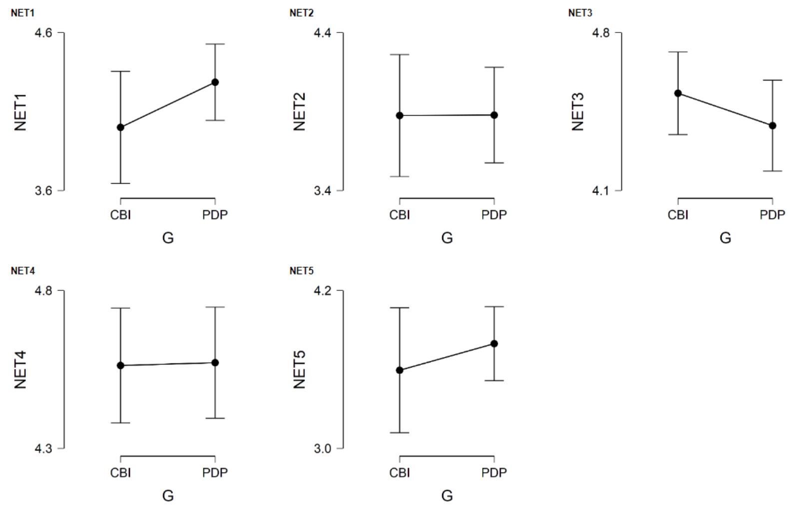


Figure 83. Networking Competences Results, CBI vs. PDP. Group means and 95% confidence intervals. Labels NET1 to NET5 correspond to skills of the Networking dimension (21 to 25)

Table 48 displays the top 5 highest ranked competences in both courses. There are 3 which are common for both courses, and it is remarkable that in both cases the top 1 is the same one.

	CBI		**PDP**	
Rank	**Competence**	**Score**	**Competence**	**Score**
1	24 - I am able to work in multicultural environments	4,56	24 - I am able to work in multicultural environments	4,57
2	23 - I am able to work in multidisciplinary environments	4,53	14 - I listen to teammates	4,43
3	4 - I evaluate the advantages and disadvantages of actions	4,53	23 - I am able to work in multidisciplinary environments	4,39
4	10 - I persistently pursue the goals	4,41	16 - I collaborate actively	4,29
5	14 - I listen to teammates	4,34	21 - I apply ethical values	4,29

Table 48. INCODE Rubric 5 – Highest ranked competences in CBI vs. PDP

As shown in the tables and figures, the only relevant differences were observed in the first dimension, Individual Competences. Among this group of skills, for competence number 3 "I present new ways to implement ideas", the difference is 0.31 (7.5%, p=0.005) towards CBI. Number 4 "I evaluate the advantages and disadvantages of actions" displays a difference of 0.45 (9.9%, p=0.003) also in favor of CBI. Number 10 "I persistently pursue the goals", has also a difference in favor of CBI of 0.28 (6,4%, p=0.0036) and number 11 "I take daring yet reasonable risks" has a difference of 0.46 (11.7%, p=0.01) for CBI, being the biggest difference.

At some distance, competences 1, 5 and 7 have non-negligible differences: Number 1 "I present ideas that are suitable for the task" displays a positive difference of 0,19 (4.4%, p=0.104), number 5 "I identify relationships among different components of the task" has also a positive difference of 0.24 (5,7%, p=0.104) and competence number 7 "I use available resources ingeniously" gives a difference towards CBI of 0.31 (7.7%, p=0.087). All of them, mainly the first 4, have a strong innovation and entrepreneurship character, while most of the competences of dimension 2, Interpersonal competences, are close to the generic Teamwork and Leadership competences. The one with the lowest p-value and a non-negligible difference of 4,9% towards CBI (competence 18, "I take initiatives") could also be considered closer to the innovation & entrepreneurship character. Finally, competence number 21, from the Networking dimension "I apply ethical values" is the only one with a slightly significative difference in favor of PDP, with -0.29 (-7.1%, p=0.083).

It is worth to highlight that the answers to the survey reflect the self-perception of the students from CBI and PDP. It is, of course, related with what they are taught and with the type of projects and methodologies used during the courses. But both groups are aware of participating in a singular course, which is different of almost all the other courses they enroll to. CBI is certainly a singular course, but PDP as a mandatory course is also non-so-common in the south of Europe, and also different of all the other courses students take during the Telecom Engineering degree.

Comparing the overall aggregated answers, the total average score of CBI is 4,09 and for PDP is 4,03. The difference between the two means is only 0,06 representing only a 1,5% in favor of CBI. The p-value is 0.06, in the borderline of rejecting the null-hypothesis, and the very small difference is almost significative probably due to the reduction of the standard error due to the big number of aggregated answers, so we cannot take it into account.

4.3. Results of the NPS – Net Promoter Score

Opportunistically, as an extra question to the INCODE survey, it was included as a separate and final question in the survey sent to the students the question "On a scale of 0 to 10, how likely are you to recommend this course to a friend or a colleague?". This question is an adaptation of the Net Promoter Score, better known as NPS, "On a scale of 0 to 10, how likely are you to recommend this company's product or service to a friend or a colleague?". The NPS is a tool used to measure the loyalty of customers to a company based on their recommendations. It is an indicator created by Reichheld (2003) and published first in the Harvard Business Review. Since then, it became an industry standard to measure the loyalty or satisfaction of a client with a brand. This same question was used to understand PDP and CBI students' satisfaction with their experience. In this scale of likeliness of recommendation from 0 to 10 (Figure 84) according to the results the clients (students in this case) are classified into promoters, passives and detractors (Table 49).

DETRACTORS	PASSIVES	PROMOTERS
'Detractors' are those who respond 6 or less. They are not particularly satisfied by the product or service. They will very like not use the service again and, could potentially damage the company's (course)	'Passives' are those who respond with a 7 or 8. They are somewhat satisfied but could easily switch to a competitor's offering if they have the chance. They probably wouldn't speak negatively about it but are not excited enough to	'Promoters' are those who respond with 9 or 10. They love the company's products and services (course in this case). They would repeat if possible and are the enthusiastic and would recommends the

reputation through negative word of mouth.	actually promote the product/service (course).	company products and services to other people.

Table 49. NPS classification

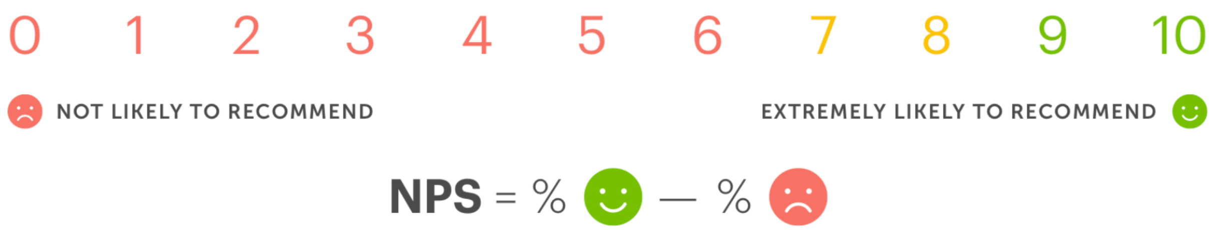


Figure 84. NPS scale (Retently, 2020)

The NPS (Net Promoter Score), is obtained by subtracting the percentage of detractors from the percentage of promoters, that generates a score between -100 and 100.

There are many authors that have questioned the NPS considering too simplistic (Keiningham et al., 2007, Hayes, 2008 and Morgan & Rego, 2006). Nevertheless, it is widely used across many industries and despite its simplicity, it is a very useful tool and easy to use tool. The answers to the NPS are as shown in Table 50.

PDP	10	10	8	2	10	9	9	10	9	7	8	9	8	2	10	6	8	7	8	7	7	8	10	8	9	10	10	10	9	9	7	10	10	9	10	9	9	9	10	9	9	8	6	7	9	9	7	7	7
CBI	9	2	10	9	10	10	7	10	6	9	8	10	9	8	8	10	9	10	7	9	8	10	9	8	10	10	10	10	9	9	10	10																	

Table 50. Total NPS responses

As shown in Tables 51 and Table 52, in PDP, the number of promoters is 28 out of 49 (57%), passives 17 out of 49 (35%) and detractors 4 (8%). In CBI, the number of promoters is 23 out of 32 (72%), passives 7 out of 32 (22%) and detractors 2 out of 32 (6%).

This makes an NPS of 49 for PDP, obtained of subtracting the number of promoter (57%) from the percentage of detractors (8%). On the other hand, CBI has 23 out of 32 promoters (72%), 7 out of 32 passives (7%) and 2 out of 32 (6%) detractors, which makes an NPS of 66 for CBI.

PDP	Promoters	Passives	Detractors
49	28	17	4
100%	57%	35%	8%
PDP NPS: 49			

Table 51. PDP NPS results

CBI	Promoters	Passives	Detractors
32	23	7	2
100%	72%	22%	6%
CBI NPS: 66			

Table 52. CBI NPS results

4.4. Discussion

Despite there is a hype on innovation in the last years, and many companies and professionals claim to innovate and mention innovation even as part of their values, we could argue that not many have a complete understanding of what it takes to actually innovate. Although the popular association of innovation with technology and startups, innovation is way more than that. Innovation is about people. Of course, in many fields, technology is fundamental to innovate but you could also innovate without technology. Nevertheless, you cannot innovate without people. And as a society, we need innovation and we need people trained to make innovation happen, beyond the folklore of the post-it parties and the ideation sessions and brainstormings.

Innovation is fundamentally about creating value, and to bring this value into the society. We need people trained in understanding people and society's needs, to develop strategies that turn into products, services or processes that have a positive impact on the society. We need people trained on creativity as well as in project management, oriented to bring these creative ideas into real solutions. Innovation is not (only) about having ideas, is about execution. It's about making these ideas a reality. Thus, we need to plan, organize and execute into projects to make ideas happen and to reduce the risk of innovation. On the same line, we need to make future professionals aware of the economics (business sense) and social impact of innovation, as any innovation project whether it is for profit or not, would certainly need a business model behind to make it sustainable. And it would also have an impact in the society and for the environment, so it is important that future professionals are aware of the impact both from the economics and the societal and environmental implications of the products, services or process they will develop.

As innovation is greatly based on experimentation and knowledge discovery, it is fundamental to develop these skills in future graduates, encouraging them to try and experiment different paths for exploring possible solutions. It is important to foster experimentation, minimizing or eliminating the fear of failure. Experiments, if well managed, are a great source of learning for innovation and problem solving comes when understanding the results of these experiments. Through experimentation, dirty prototyping and quick testing, innovation speeds up and the risk of investing too much time and effort in developing non-impactful solutions is reduced.

Innovation is not a one-man-show. We need people able to work in teams, and specially in multidisciplinary teams in order to understand every angle of the challenges we face and to be able to collectively build knowledge. And for effective teamwork, communication is key. It is important to foster communication skills within teams, and to promote oral presentations in front of others (colleagues, professors, clients, institutional representatives, companies' representatives...), to allow future professionals to effectively communicate their ideas not only to their team members, but also to other stakeholders. Also, more and more, innovation is tending to be collaborative, not only within teams of the same company or institutions, but among multiple companies in open-innovation strategies, sharing knowledge, risks, costs, and benefits. Thus, it is very important to develop in future professionals the networking skills, to have the ability to find and interact with relevant stakeholders, partners, or players.

It is important to train future graduates in managing uncertainty, as it is an inherent part of innovation. If we know the answer upfront, if we know what needs to be developed, we are probably not speaking about innovation. Thus, we must teach students how to manage uncertainty, to make the right choices and avoid giving hasty answers to complex challenges.

Also, innovation takes to assume risk and it is important to teach future professionals to properly gauge these risks, giving them the tools and making them aware of the levels of threats in order to them making balanced decisions to assume controlled risks.

We need to train people to lead innovation and thus, to lead change. Leadership is a key competence for innovation and needs to be fostered. Also, even though it is not mandatory for innovation, entrepreneurship is a competence that needs to be developed in graduate students. Entrepreneurship is probably not for everybody but is good that future professionals are formally trained in it. On one side, the more people discover entrepreneurship the more chances of well-prepared entrepreneurs to be successful on bringing innovation to the society. On the other side, even though they don't intend to be an entrepreneur, they will understand what's needed to bring ideas into the market, be it in a startup, a corporation, or an institution, and this would eventually make it easier to us as a society to create positive change through innovation.

On a more individual level, skills like critical thinking, self-efficacy and self-awareness are important for innovation. Critical thinking needs to be developed in order to question the status-quo and consider all the implications of any innovation challenge. Self-efficacy and self-awareness are also very relevant, as here lies the understanding of a person's abilities or capacities, and the belief of what they are capable of doing or achieving. If future professionals believe they can make a positive change, it is likely that they can do it. If they don't, then it would be almost impossible for them to make this change.

It can be said that, as it could be expected, both analyzed methods (project-based and challenge-based) are good educational strategies for developing competences and, explicitly, innovation competences in engineering education, but each strategy help to develop some competences more than others. It is worth to highlight that one of the limitations of this research is that all the data analyzed are post-test, without having a starting assessment. Although it was not possible in our study, for further research it would be recommended to have a pre-test and post-test, in order to compare student's innovation competences before and after the courses. This would give a more accurate measurement of the impact on innovation competences of both type of courses. Also, it is important to mention that by default all students should initially take the PDP project course, but the CBI course is offered as an alternative way of doing it. For being accepted to CBI they need to proactively opt for it, and they have to present their grades and a motivation letter. This poses a potential risk for the study, as CBI students may already have a certain bias or motivation to better develop innovation competences versus PDP students. This risk is also mitigated as PDP course runs twice a year (Fall and Spring terms) and CBI only runs once a year (Fall term), being that students taking the project-based course in the 2nd semester cannot opt to attend CBI. In addition, most students enrolling in CBI acknowledge that their initial main motivation is the relationship with CERN, rather than innovation or entrepreneurship.

As mentioned in the introduction, having one group focusing almost purely in engineering and technical projects (PDP) and the other one focusing on innovation challenges with a wider perspective (CBI), with specific training sessions in broader innovation competences like user research, ideation, creativity, business modeling and entrepreneurship, lead us to expect big differences between the analyzed courses. In our initial hypotheses, very different outcomes were initially expected from courses regarding innovation competences, given the different approaches and teaching methodologies between CBI and PDP courses. The differences found in Planning and Managing a Project, Leadership & Entrepreneurship and Creativity in the qualitative analysis are aligned with the initial hypothesis. But our study also revealed that as well as CBI, PDP greatly contributes to develop all other innovation competences. Nevertheless, the differences obtained with the INCODE Barometer are not as big as expected. As general conclusions of this quantitative survey, we would highlight that both courses gave as result a good self-perception of the learning outcomes in the innovation-related skills, according to the results of the INCODE Barometer, with all individual means above 3,5 out of 5 and being the overall mean of the aggregated results of 4 out of 5 in both groups. The differences found between CBI and PDP groups in the self-perception survey are small and only moderately deviated towards CBI (4,6%) in the individual competences dimension. Although teachers and supervisors have the opinion that the learning outcomes of CBI students in innovation-related skills are higher than the PDP students' ones, this difference is small in the self-perception of students.

It is worth to highlight that PDP students (only engineers) do not have a reference of students of other disciplines with higher skills for comparison, and do not have to face the same kind of conflicts or challenges than the CBI students. Thus, we can conclude that in terms of improvement of self-confidence regarding innovation competences, both types of courses contribute significatively with independence of the approach, scale, mix of students and type of projects. The common features of both analyzed courses are teamwork, contact with the real world, interacting with stakeholders that are external to the educational institution, and some kind of multidisciplinarity, together with the feeling of carrying out a singular experience.

Nevertheless, when analyzing the results of the qualitative content analysis of the reflection documents, the differences between both courses are more evident, still showing that both CBI and PDP contribute greatly to developing innovation competences. Also, some interesting contradictions (although with small mean differences and high p values in the quantitative analysis) are found between both quantitative and qualitative analysis that are worth mentioning. These are analyzed and dissected in the following paragraphs as part of the mixed methods approach.

As shown in literature, the apparently contradictory results of some aspects of the quantitative study vs. the qualitative study are something rather common in mixed methods research (Robey, 1995, Gallivan, 1997, Mason, 2006, Slonim-Nevo, V. & Slonim, I., 2009 and May, 2010). Robey (1995) defined a framework for understanding contradictions in mixed methods research, that was later expanded by Gallivan (1997) into 5 categories:

- Contradictions that appear within a study due to the use of mixed methods
- Contradictions that appear within a study, but the contradiction is identified one a single method alone (not due to using mixed methods)
- Inherent contradiction within a study, where some results are inconsistent with previous research
- No contradiction within the study, where a synergy exists between the results of the mixed methods
- No contradiction within the study, where parallel results are not synergistic between the mixed methods

According to Gallivan (1997), when using mixed methods independently, there are greater chances to generate inherent contradictions between two sets of results within a single study, as opposed to using sequential mixed methods. This is because in the first case (independent mixed methods), when collecting and analyzing data, findings are more likely to diverge or contradict each other. In contrast, when collecting and analyzing data sequentially, the researcher has the opportunity to adapt the procedure and focus of the analysis to ensure consistency in the results, reducing the likelihood of inherent contradictions. But also, several authors mention that contradictions between two methods, if resolved, lead to more interesting findings (Davis 1971; Poole and Van de Ven 1989; Robey 1995). In our case, the studies were carried our independently and in parallel, as the survey was launched in July 2019, while in parallel the content analysis (which has started earlier) of the self-reflection documents was being carried out. Thus, there were no intentions to use one method to “validate” the findings of the other.

On the same line, May (2010) discuss three approaches to mixed methods for the issue of contradictory data and their implications: triangulation, complementarity and constructing multidimensional explanations.

Triangulation is regarded as the “classic” approach in mixed methods research, where findings from one method can be validated with another method (Denzin, 1977). In this sense, triangulation aims to a more accurate and better approximation for understanding a social phenomenon. Although this is desirable and might sound “more scientific”, there is a metaphor often used to describe triangulation that says that “trying to create a three-dimensional representation by combining two two-dimensional images is problematic”.

Complementarity in mixed methods is when the studies, rather than a corroborative approach look for an integrative logic. It is aimed to asking questions about connecting integrated aspects of a “social phenomenon that complement rather than validate each other, like the pieces of a jigsaw puzzle (Mason, 2006)”. Nevertheless, social reality representations are not provided by the methods. What they provide are constructions of this social reality. And these images are dependent on the techniques employed by the researcher. Consequently, as argued by May (2010), combining methods is not a good approach for cross-validations or triangulation purposes, as they are not able to produce on picture of reality.

Finally, according to the third approach, constructing multidimensional explanations, given that social phenomena are multidimensional, they should not be studied in a single dimension only (Mason, 2006). And with conflicts, the author mentions that there should be no push to determine which one is more “correct” than the other, but rather interpret them in context as different viewpoints of the same issue/phenomena.

Different dimensions might intersect in multidimensional explanations, but they could also exist in tension with each other. As suggested by Mason (2006), although this could be interpreted as a contradiction, this is not necessarily a bad thing, as it can help to the construction of “dialogic” explanations capturing the “dynamic relation between more than one way of seeing”. This author speaks about “linking data” or “meshing methods” than of integration, without the aim of producing a tidy picture, but rather allowing for the messiness and tensions that exist in social reality. It argues that “explanations do not have to be internally consensual to have meaning”, and that if the social experiences are multidimensional, then explanations need to be too. And how these dimensions or “contradictions” emerge and intersect, depend on the questions being asked and the theoretical orientations underlaying those questions.

As our research used mixed methods independently, without the aim of using triangulation or complementarity, we opted for the third approach discussed by Mason (2006), of constructing multidimensional explanations to analyze the different dimensions of the phenomena under study.

When looking at the results of the qualitative analysis of the reflection documents, the bigger differences are found in Planning and Managing Projects, Leadership & Entrepreneurship and Creativity. In the following lines we discuss the conclusions regarding these differences.

To understand the bigger numbers on Planning and Managing Projects competences in PDP, it is worth to highlight the fact that in this course is aimed to achieve a technical solution to a clearly defined industry problem from a company. Thus, students focus more on a traditional project management approach and on problem solving and technical/technology development. All emphasis is put into execution and not in exploration (Loch et al., 2006). Also, PDP has more demanding requirements for project planning and reporting, including bigger teams (9-12 people in PDP vs. 5-7 in CBI), elements which might influence this difference. Also, for the CBI course, the project plan is implicit in the Design Thinking methodology steps, and the students are asked to report the intermediate results with short presentations instead of formal reports. These short presentations are not perceived by the students as a documentation method, unlike the formal reports are.

The fact that Leadership & Entrepreneurship competences are more developed in CBI is probably due to that in most PDP projects the sponsors or clients pose very specific technical problems, with very concrete requirements of current business or industry needs. Thus, PDP students do not consider or need to employ entrepreneurship competences because they work on a technical solution within a very well-defined framework of an existing company. On the contrary, CBI students, even though they have project sponsors (yet not in all cases), are given challenges that are wide open and do not sit on short-term specific industry/company needs or requirements. This openness allows students great freedom in the solution space (Rattcliffe, 2009), making it possible to develop solutions integrated (or to integrate) in existing companies' processes or creating hypothetical startups that would develop and market the solution. In addition, another relevant fact is that UPC (engineering) students are exposed to business and entrepreneurship sessions from ESADE (business) professors. Finally, having MBA students and designers in the same teams with the engineers and interacting together with other stakeholders, as it is likely the case in a real startup, has a positive influence in developing leadership and entrepreneurship competences.

The fact of having an external institution, either a company, a startup or any entity from outside the school proposing a challenge or project briefing provides a great sense of reality and develops a greater engagement and sense of responsibility in the students. It provides them a real practice in what could be typical projects they would face when graduating and start working at a company. On the other hand, if instead of having companies putting challenges, the framework is broader like the SDG-Sustainable Development Goals from UN (like in CBI), this brings another perspective and greater learnings and focus on the social impact of student's projects, as opposed to PDP where the focus is on a technical issue from the industry. Also, not having a "client" with clear requirements, allows the entrepreneurial spirit to naturally raise in the students. As what they develop is not for an existing company, and the solution they create has not an existing channel for going to market, the idea of creating a hypothetical startup that would market that solution is more likely to appear. On the contrary, in PDP like projects, the idea of building a startup only makes sense when the institutions are not the ones developing the product/service (as in the case of NGOs or hospitals) while in the projects stated by industrial or services companies, the students' business model is more likely an engineering consultancy.

On the other hand, PDP students in general have interlocutors, both from the company and from the supervisors' side, that are technical staff and engineers. Probably that is why there is no evidence or mention of entrepreneurship in PDP, whereas there are 21 coded segments found in CBI. This is in line with the results discussed by Palomäki (2019), which demonstrated that CBI has a positive impact on the entrepreneurial intentions of the students participating in this course. Regarding leadership, even though that PDP teams are required to define a project leader and CBI teams are not, there are more findings in CBI related to this competence. As in this type of challenge-based course the level of uncertainty is higher (Malmqvist et al., 2015) and tasks and deliverables are less defined, students' leadership is triggered as they need to find the answers and define what to do by themselves.

Also, when looking at the INCODE self-perception survey, in the Individual competences dimension (Table 46), there are two that can be related with Leadership and Entrepreneurship that have better results in CBI. These are *10 I persistently pursue the goals* with a 0,28 (6,4%) difference a p=0,036 and *11 I take daring yet reasonable risks*, with a 0,46 (11,7%) and a p=0,01 in favor of CBI. Also, in the Interpersonal competences dimension (Table 47), the only competence that gives a p value in the border of 0.1 with a positive difference of 4,9% towards CBI is number *18 I take initiatives*, which is related to leadership and entrepreneurship. This is consistent with what is found in the qualitative analysis.

When referring to the word frequency of the analyzed documents in the qualitative analysis (Table 42 and Table 43), it is very interesting to observe that both courses have the same three words in the top 3 (*project, work and team*). In the fourth position is where the differences start to arise. In CBI, the word *think* is in position number four, while the same word in PDP is in position number 23. This does not mean that in PDP students do not think. They obviously do, but when it comes to facing a challenge-based project (CBI) vs. a product development project (PDP), the amount of time dedicated to reflecting on the problem and how to tackle it, is notably more important in CBI.

Most important is the difference found with the word *idea*, that in CBI it is in position number 5 and in PDP is in position number 46. This is probably the biggest different between both courses regarding word frequency, that represents the backbone of both courses. While in CBI students devote an important amount of time to reflect of the problem (challenge) and discuss ideas on how to solve it, in PDP students jump straight into the solution. PDP students do, of course, reflect on the problem to solve it, but with a narrow and technical approach, with a clear path forward in mind. This is observed in the other words in the top 10 of PDP: *result, system, problem, member* and *document*. This last one highlights the importance of the documentation and the deliverable of the project more than the project result itself. In the case of CBI, the words referring to solution come in positions 13 to 15 (*technical, problem, solution*).

In CBI, the other words in the top 10 are *people, cbi* and *experience*. The word *people* refer to the social impact and user centricity sought with CBI projects. The words *cbi* and *experience*, refer to the unique learning experience that the students are aware of being living with this course.

In the top 10, the other words that both courses share are *time* and *learn*, which obviously refer to one concern of all students (time is never enough) and the ultimate outcome: they evidently learn a lot with these two experiences, and they are aware of it.

Interestingly, in position 11 in CBI it is the word *engineer*, which shows the reflection of the self-perception of the students regarding their profession and the value they provide to the group. This word does not appear in the top 50 of PDP most frequent words.

Creativity is also notably more evidenced in CBI in the qualitative analysis (22% in PDP and 78% in CBI). Factors like learning the Design Thinking process in CBI with its dedicated time slots for idea generation and iteration, as well as specific sessions with tools and methodologies for ideation definitely make a difference in developing this innovation competence.

Surprisingly, in the INCODE self-perception survey, PDP score in competence number *2 I present creative ideas is slightly higher* (3,86) than CBI (3,75), where they follow a Design Thinking process with dedicated classes to creativity and ideation. Although the mean difference is only -0,11 (-2,9%) with a p of 0,2890, it is a result that could not be explained without the qualitative analysis.

This higher perception about creativeness of PDP students (working in groups of only engineering students) could be due to the fact of having more degrees of freedom than in the regular courses. On the other hand, CBI students work in multidisciplinary teams, composed by designers, engineers and MBA students. Thus, CBI engineering students, although being trained in creativity techniques and participating in creative tasks, compare themselves with people more trained in creativity skills, acknowledging that they might not be as creative as the other disciplines' students. This could partially be a result of what is known as the Dunning Kruger effect (Dunning et al, 2003). It is a "cognitive bias whereby people who are incompetent at something are unable to recognize their own incompetence. And not only do they fail to recognize their incompetence, they're also likely to feel confident that they actually are competent" (Murphy, 2017). This effect is produced due to people's performance perception is based partly in their preconceived notions of their own skills.

The same Dunning Kruger effect might explain competence *20 I face conflicts with flexibility to reach agreements* and *23 I am able to work in multidisciplinary environments results*. Thus, it is worth to highlight that for this type of self-perception studies is good to complement them with other methodologies (like in this case, qualitative content analysis), as they could be influenced by a biased performance perception due to the fact that students are not experts and not fully aware of the total depth of knowledge in the field of study.

Derived from the lack of multidisciplinarity and working with like-minded people (only engineers), might be the reason behind for competence number *20 I face conflicts with flexibility to reach agreements* to perform slightly better in PDP (4,02) than in CBI (3,94). Given that in CBI the mindsets and backgrounds of the team members are so different, the way to approach and solve problems or conflicts is also very different, being not so easy to reach agreements and having to learn the language and mindset of the others.

Speaking specifically about multidisciplinarity, when scoring competence number *23 I am able to work in multidisciplinary environments*, it is remarkable that for PDP is the third highest ranked competence (in CBI is the second). This is probably due to the fact that most PDP projects involve ICT engineering students from different minors (Networks, Communication Systems, Electronics). While the differences among them are really small, they perceive the experience as multidisciplinary because it is the only course in which they mix together. On the contrary, CBI students work in real multidisciplinary teams, where engineering students mix with design and MBA students.

Remarkably, whereas in the INCODE self-perception survey, the competence *23 I am able to work in multidisciplinary environments* obtains a mean difference of 0,14 (3,2%) in favor of CBI, in the content analysis the mentions related to multidisciplinarity are 102 in CBI vs. 1 in PDP. Meaning that when asked (in the survey) the students are forced to answer to it (and they do it with a high value), but when they are asked to perform a free reflection document, the multidisciplinary aspect of PDP is neglected. Even though it is consistent (more in CBI), the difference is huge. As mentioned above, we could say that the Dunning-Kruger effect might be the explanation to this paradox. In this same line, it is curious that competence *24 I am able to work in multicultural environments* gets almost an equal result in the INCODE survey in Table 48 (4,56 CBI vs 4,57 PDP) while clearly PDP has vast majority of Catalan students (with some exceptions) vs. CBI where UPC students mix with ESADE and IED students, where the proportion is the opposite, being the vast majority not only not from Catalunya, but from many different countries, typically up to 20 different nationalities for a set of 50-60 students.

Impact innovation competences appear to be more developed in CBI, as shown in the qualitative study (Figure 64 and Figure 65). CBI course has more emphasis on social impact due to focus, especially since in the last years the challenges has been framed around the United Nations Sustainable Development Goals (SDGs, 2015). The students, therefore, have to reflect more on the end-to-end implications of the solutions they are developing. Also, regarding business sense, the fact of being in contact with MBA students and having specific classes on this from ESADE clearly make a difference. Similar to what it happens with creativity, there is a contradiction on the results of the qualitative analysis (and what is observed by the teaching staff) and the self-perception survey results. In the survey, the awareness of ethical values for both courses is shown in competence number 21 *I apply ethical values* and 22 *I take into account the implications of the task for society* (Table 48). In competence 21 the score is higher in PDP (4,29) than in CBI (4,00) (difference -7.1%, p=0.083) while in PDP, decisions are mainly based on "cold" business or technical facts, without a focus on social aspects, because the topics of the projects are real companies challenges with engineering focus (i.e., developing a sensor for 3D printing machines). But PDP students are also asked to perform a social, environmental and economical sustainability analysis of their project, following the directions given in a specific seminar about the topic, so they are aware about covering the issue although they do it in a quite superficial way. In competence 22 (Table 48) the results are the same. On the contrary, in CBI they work fully immersed in social challenges, with way more "human" implications and putting the students in contexts of challenging also their values when developing the project (i.e., access to water in rural Ghana), and their self-perception is similar and even lower. Again, the Dunning Kruger effect might partially explain this contradiction.

Regarding networking competences and its neutral differential response in the INCODE survey (Table 48), while CBI students have to find contacts and perform interviews with relevant stakeholders (e.g. CERN scientists, UN agencies in Geneva, top staff members in the industry, …), PDP students have also contact with external institutions (staff at hospitals, mid-level company representatives, project managers, city-council officers, …). Although the level and intensity of the contacts is different, both have the perception of having reached a satisfactory level of skills and certainly have improved them at the end of the projects. In the content analysis of the reflection documents, networking competences found are not as many as in other competences with only 79 mentions (Figure 66 and Figure 67) , but in the evidence found there is more in CBI (71%) than in PDP (29%). One of the reasons for this difference is probably the relationship with CERN and its scientists in CBI, which is quite unique, and highly valued by the students. Also, the inherent uncertainty of CBI projects, that forces the students to develop themselves their contacts and networking as opposed to PDP where contacts are mostly given.

Finally, regarding the experience of the students from both PDP and CBI reported through the NPS (Net Promoter Score), according to Retently (2020) just having the number is not relevant, as it gives not enough information and there are so many factors influencing this result. Nevertheless, in the NPS scale (Figure 85) it is stablished that from -100 to 0 is a bad NPS and needs improvement, from 0 to 30 is a good NPS, from 30 to 70 is a great NPS and from 70 to 100 is an excellent NPS.

Figure 85. What is a good NPS? (Retently, 2020)

Depending on the sector, the average NPS varies a lot. For example, according to a study from the company Temkin from 2018, for auto dealers in the USA, the average NPS is in the range of 39, while the average NPS for Internet Service Providers is the range of 0.

Thus, the NPS is useful for comparing within one sector, against competitors or against oneself, to understand whether the improvements made to our product/service has an impact on user experience and if it reflects on the NPS.

Although there are not so many specific NPS studies in engineering education, we can refer to Sripakagorn et al. (2014), where in a CDIO (Conceive - Design - Implement - Operate) implementation in a mechatronics course in the Chulalongkorm University of Bangkok, obtained an NPS of 81 from students after the course.

In our case, the basic conclusions are that both courses are within the Great range and that CBI performs better (66) than PDP (49) on students' satisfaction or students experience as shown in the NPS results. Also, comparing to the case of Chulalongkorm University, they have a small NPS, but this cannot be considered as a "sector NPS" or a reference, as it is only one case.

To better understand the differential value of these courses, it would be recommended to extend the NPS survey to other UPC courses. That would give an NPS for each course and would be easy to compare the perception or student satisfaction among the different courses. Also, it would be very useful to have an NPS survey after every edition of PDP and CBI courses, to compare year to year the evolution of the courses.

In summary, both project-based and challenge-based projects are good educational strategies for developing innovation competences in engineering education. Nevertheless, depending on the chosen pedagogy some competences might be further developed. Following a traditional project-based course shows better results in Planning and Managing Projects related innovation competences. For Creativity, Leadership & Entrepreneurship, a challenge-based combined with Design Thinking approach reinforces the development of these competences.

Chapter 5 – Conclusions and recommendations

5.1. Conclusions

This study summarized the innovation competences needed for engineering students and confirms that experiential learning experiences like project-based and challenge-based education combined with Design Thinking are methods that successfully contribute to developing the aforementioned innovation competences, answering our initial research questions.

As shown in our research, all the aforementioned innovation competences are developed by the students in either project-based courses (PDP) or challenge-based (CBI) courses, but depending on the approach, some skills are more developed than other. Thus, we can say that regardless of the effort and resources needed to develop these experiential learning experiences, it is worth to promote these types of courses (either project-based or challenge-based) to develop innovation competences on engineering students much needed by the industry and the society. As demonstrated in this study, following a traditional project-based course is better suited for developing Planning and Managing a Project related innovation competences and Experimentation & Knowledge Discovery. For developing Creativity and Leadership & Entrepreneurship competences, a challenge-based course combined with Design Thinking approach would be a better choice. Finally, both methods are similarly appropriate for developing all other innovation competences related to Teamwork, Impact, Personal & Professional Skills and Networking.

Also, it is worth to mention that although the INCODE Barometer is one of the few available tools, using self-perception questionnaires like the one used to measure the innovation skills has the risk of biasing the answers by the sole reference to the skills made in the statement of the questions. For example, just by the fact of mentioning creativity, automatically raises the awareness of the students responding to the survey and forces them to evaluate their level on this competence. Maybe, if this topic was not raised, the student might not even mention creativity as a learning outcome. That is why we think it is important mixing self-perception surveys with other qualitative methods to have a better picture of the phenomena, as done in this thesis, by combining the INCODE Barometer Rubric 5 self-assessment survey with qualitative content analysis of students' reflection documents in a mixed methods approach.

Another relevant finding of this research is the Dunning Kruger effect, observed for example in the biased self-perception of PDP students' competence observed related to skills like creativity (as they are not trained in this) versus CBI students which rate themselves lower, while they are actually trained in it. This leads us to conclude that when teaching some specific content, it is important to make students aware of the vast breadth and dimension of the field related to the topic. To avoid or minimize this Dunning Kruger effect, if students are shown that they are just skimming the surface, they will be more conscious of their limitations and capacities concerning the competences under discussion, helping them better understand risks and making better judgment of future situations. Maybe also, this Dunning Kruger effect is not only related with the level of knowledge of an individual, but also with its own personality and youth.

According to CBI engineering students' feedback through surveys, personal reflections and observation from the teaching staff, the most valuable learning outcome, is being in contact and working in teams with students of other disciplines really make a difference (above the international experience and the singular environment of CERN with the possibility of contacting high-level scientists and technologies). They highly value knowing the way the others think, their tools and methods, being able of giving the right value to the other's work and developing a common language. They perceive this as a "real life professional experience", as they are aware that in this type of teams is how they will really work when they graduate, interacting with people from different disciplines. As one student mentions about his main take away from the course: "How to work with people from other disciplines, understanding their points of view, in order to come up with the best solution to a problem not only from a technological approach". The understanding of innovation beyond technology and engineering is one of the great achievements of this learning experience for engineering students.

In opposition, in PDP multidisciplinarity is considered as mixing electronics and networks, communication or audiovisual systems engineering students, which at the end are all ICT engineering students, with some differences of course, but with the same mental framework. This multidisciplinarity is better than just having students from a single engineering discipline but does not make the students learn how to work with people with a different mental framework and from a completely different discipline, which is a very relevant experience for professional life and for making innovation possible.

In the specific case of engineering students, in addition to the multidisciplinary values, there is a clear improvement in self-confidence and a clear increase of user-awareness. Also, they gain a broader understanding of the value delivered by a product or service, on top of the technical functionality. It was observed that in CBI, when starting the projects engineering students in many cases take a more reactive role. As they are not trained in user research or market research, they expect the other team members (design and business students) take the lead in the Discover phase of the project. They expect others to tell them what to do, in a kind of "tell me what to build or what to code and I'll do it" approach. Another great outcome of the CBI course is eliminating this attitude and get the engineering students to engage with user research and interviews, engaging with real user in real environments, understanding needs and defining strategies. Their leadership is enhanced and developed, having them engage and discuss about business models and social impact at the same level of design and business students. They also realize about their own value as professionals, as the other team members rely on them as the ones that are "going to make things work", so they feel the responsibility of delivering a professional opinion and solutions that address not only the technical problem, but considering all aspects: user needs, design, busines model, social impact, etc.

Not all engineering students are prone to become entrepreneurs. Educational experiences like CBI will not only develop the entrepreneurship competence of the ones that are already interested in entrepreneurship but could also trigger the entrepreneurship gen in those who were not aware of it. The goal is to identify those who are through the exposition to CBI-like experiences and provide them experiences to enhance the innovation and entrepreneurial skills. In any case, being exposed to entrepreneurship is positive for all, as they understand the dynamics and challenges of it. In some cases, they will go further and pursue entrepreneurship and in other they will not, but at least they will know what to expect when facing with it in any aspect of their professional life.

There is a tradeoff that needs to be well balanced: the dedicated time for direct contact with users improves the creative part (needfinding, ideation) but reduces the time for designing complex solutions and its associated learning outcomes. Then, with limited time and resources, engineering educators should choose between focusing more on entrepreneurial skills or technical skills. The (not so) standard PDP courses would provide tools to get the learning outcomes of analytical design, and devote more time for developing the technical solutions, but missing the value of empathizing with users, understanding in depth-needs and penalizing creativity A possible logical scenario could be to dedicate one semester to a CBI like course and afterwards a PDP like course with the same challenge. Nevertheless, the complexity and abstraction needed to perform CBL is higher than the one needed to follow a PDP course. Thus, the reverse order would be more suitable, although having different project topics would be recommended. If the program syllabus cannot allocate this arrangement for having the two types of courses, it would be good for students to have the ability to choose between them, with enough information about the kind of learning outcomes of each modality.

The fact of having an external institution (company, a startup or any entity from outside the school) provides a great benefit for these types of courses. It gives a sense of reality (as they actually are real) and develops a greater engagement and sense of responsibility in the students. When the challenge or project briefing is proposed by an established company or institution, the needs and specifications are clearer and more accurate to their business or industry challenges. This helps to narrow faster the project and to work in a more realistic, constraint wise environment. The benefits for the students here are to work in more "standard" or business as usual projects, providing them a real practice in what could be typical projects they would face when graduating and start working at a company. This is the case of PDP projects, where typically companies place a technical challenge for students to work on.

On the other hand, instead of having companies putting challenges there could be a broader framework, like the SDG-Sustainable Development Goals from UN (like in CBI since 2017). This brings another perspective and greater learnings and focus on the social impact of student's projects, as opposed to PDP where the focus is on a technical issue from the industry. Also, not having a "client" with clear requirements, brings another interesting perspective in place, which is the entrepreneurial spirit that naturally raises in the students. As what they develop is not for an existing company, and the solution they create has not an existing channel for going to market, the idea of creating a hypothetical startup that would market that solution. On the contrary, in PDP, the idea of building a startup is very rare if not inexistent. They work for a company and it is clear that is that company that would use or bring to the market the results of their project. The typical business model they propose is being an engineering consultancy company that performs a contract for the client company. Both approaches are a great learning experience for the students, and both have advantages, but they develop different competences in the participating students.

Engineering students' feedback regarding PDP and CBI course has been more than positive, with many of them qualifying it as a milestone in their curriculum. They mention several features that are not usually found in other courses, are altogether in CBI: multidisciplinary, not only within their teams, but also from coaches and teachers from different disciplines and educational institutions (engineering, design and business), contact with top level scientists in an unique environment with singular workspaces at CERN, intensive work periods in a studio-like approach that boost creativity and enhances focus, challenge-based projects looking to solve a societal problem, using Design Thinking as a user centric innovation approach, which take the engineering students out of their comfort zone and makes them interact with real users to empathize and understand in depth their needs. Students' feedback regarding PDP specially highlight the value of working in teams, in real projects for real companies as a key experience.

Engineering students experience the biggest difference with their previous training when participating in a multidisciplinary user-centric innovation project like CBI. And due to their natural professional bias, they tend to focus too early on the process into technical solutions and viability of the ideas discussed during needfinding and ideation (two thirds of the project duration). This requires an extra effort from the coaches and teachers, in order to maintain the scope open and avoid making technological decisions too early, when low-resolution prototypes are being developed or even concept solution ideas are being discussed. This uncertainty is stressful for many engineering students, as they are not trained for dealing with it. On the contrary, they are better trained in PDP to quickly reduce or eliminate uncertainty by early on defining specifications and requirements, or even just starting with the latter in most of their student projects.

On the same line, it was observed that is very common that engineering students tend to raise technology limitations or feasibility concerns early on the ideation phase (even some engineering teachers and coaches sometimes do it). As this is their core knowledge, they cannot avoid thinking about this, and it is obviously of vital importance that the ideas later on can be developed and implemented. Nevertheless, it is also fundamental to allow the flourishment of disruptive solutions that go beyond the current existing technical solutions. And to do so, feasibility or technology limitations issues must be disregarded at these early stages of the process.

Open-ended and challenge-based projects more than product development projects allow the students to learn how to manage uncertainty, by proactively creating information and developing knowledge themselves; reflecting on it as a group, making sense of it collectively; and adapting the project direction accordingly. This also is one of the aspects that contribute to develop entrepreneurial competences of the students.

The benefits of courses like CBI are not easy to foresee for the engineering students before participating in the course, as Design Thinking is a methodology that can only be learnt by doing. Although a full immersion in Design Thinking like CBI cannot probably be extended to all engineering students due to the high number of resources required (trained teaching staff and dedicated coaches and spaces), time and calendar restrictions, CERN availability, and coordination with other schools among others; but a basic knowledge of the basics of these user-centric innovation approach would be very beneficial for engineering students. Specially for raising awareness of innovation and entrepreneurship among them and to develop interest in participating in experiential learning experiences like CBI. Also, it is worth to mention that probably many engineering students would prefer purely technical projects like PDP, as they are not interested in business or user research. They might "just want to code" or build stuff. But, as said above, they would in any case benefit from knowing that these methodologies exist so that in their future professional careers face uncertainty, business models, user requirements or unmet user needs, they would be better prepared for dealing with it.

Finally, even though this research was focused on engineering education and ICT engineering students' projects results were analyzed, we could argue that the conclusions on experiential learning approaches for developing innovation competences could be applied to any field (not only in engineering), as discussed in literature (Marí-Benlloch, 2017), they are transversal competences that any future graduate and the society would benefit from. Being ICT an innovation driver in any field, due to the digitalization trend, with most innovation projects in any field including an APP, AI or IoT solutions, the fact of working with ICT engineering students gives an extra degree of value and reality to the projects.

5.2. Recommendations

First of all, it is recommended to implement either project-based or challenge-based courses in engineering education as they are valid educational strategies for developing innovation competences in engineering students. This recommendation is also valid not only for engineering education, but for other fields, as innovation competences are transversal skills that any professional will require. And as a society, we need people trained to innovate, to face the huge challenges ahead of us, like climate change, access to water, poverty among others, that are well summarized in the SDG from UN.

Depending on the objectives and approach of the educational strategy of the institution, one type of course or the other would be recommended to develop some innovation competences more than others. To better develop creativity, user awareness, leadership & entrepreneurship, networking and social impact awareness challenge-based with a Design Thinking approach courses like CBI, with an open-ended problem works best. For developing project-management skills, problem solving and technical/technological development skills, project-based courses like Product Development Projects (PDP), working with an external institution company putting an industry challenge, are better suited. Both CBI courses and PDP courses are equally recommended for developing teamwork and communication skills, as well as personal & professional skills like self-awareness, self-efficacy and critical thinking.

True multidisciplinary projects, mixing different knowledge fields (engineering, design, business) are highly recommended, as they have great impact on the learning experience of the students and helps them to develop greatly innovation competences related with teamwork, communication, self-awareness, self-efficacy, networking among others. The multidisciplinary experience has shown to be a successful tool to enhance the innovation and entrepreneurial competences in engineering students but due to its cost (teaching staff involved, dedicated spaces, ...), it probably cannot be scaled to all the students. But the methods developed, and lessons learnt can be partially applied to capstone projects and even to standard courses in engineering education. Thus, it is highly recommended to introduce some degree of multidisciplinary in project-based courses like PDP. Students perceive this as a “real life professional experience”, as they are aware that in this type of teams is how they will really work when they graduate, interacting with people from different disciplines.

The inclusion of intensive periods in singular workspaces, out of the regular classrooms and labs has also been identified as a key factor for success. Students’ engagement and teambuilding is taken to another level during these periods in singular spaces. The Design Factory at Aalto, Fusion Point at ESADE, IdeaSquare at CERN or the Innovation Space at the Technical University Eindhoven are good examples of these type of singular spaces.

The Design Thinking approach provides powerful tools to deal with uncertainty in open challenges, thanks to the systematic way to tackle it through iterative divergent- convergent phases and the test with users and other stakeholders. Introducing Design Thinking into a broader range of courses, like PDP or capstone projects would be recommended up to some degree. It is desirable that all engineering students get to know the user-centered innovation approach, learning how to deal with uncertainty, focus on user needs empathizing with real users, develop creativity and ideation skills, etc. But, as discussed in this research, devoting more time to the discovery phases, reduces the time dedicated to learning how to develop the technology. Thus, there should be a balance between integrating these new skills in the curricula, but without diminishing the engineering development skills. Also, it could be said that PDP would be probably more suitable for the Bachelor curricula (emphasis in procedures) and CBI for the Master curricula (emphasis in strategy), but then, Master students coming from other institutions may have not followed a PDP like course before the CBI.

On the same line, it is recommended that engineering students develop their business sense and social impact awareness of the projects they develop. Focusing exclusively in technical or technology development would limit their ability to influence strategic decisions. Thus, teaching them business related competences within project-based courses is recommended. Also, as in every aspect of today's society, we need to consider the social impact of our actions. Thus, it is highly recommended to include this knowledge and embed the skills for analyzing and raise awareness of the social impact of the projects developed by engineering students. Integrating somehow the Sustainable Development Goals (SDG) as a framework in project-based courses could be a good strategy to make the students aware of these issues when making project decisions. Even if it is a project with an industry focus and a technical scope for a company, reflecting on the aforementioned topics would benefit both the students and the institution or company placing the challenge, and ultimately the society.

Regarding experimentation and knowledge discovery, it would be recommended to foster the "fail and learn fast" philosophy of Design Thinking, to lose the fear of making mistakes and exploring a wider range of solutions, allowing some time to try dirty prototypes, and quickly iterate in the ideation phase would be very beneficial for engineering students. Trying different solution approaches, making draft prototypes or visualizations of their ideas before jumping into coding or functional prototypes, would broaden their competences on innovation.

To develop the networking skills in engineering students, it is recommended to get them out of their comfort zone by requiring them to look for answers outside their first circle of relations (professors from their department or class). By introducing this, it will force the students to find and engage with other people, either users, stakeholders, technical specialists, or any kind of people will help them to develop their networking competences.

Developing leadership skills is of outmost importance for engineering students. One way to foster this is by leaving them some degree of uncertainty and freedom, depending on the type of project-based course, so that they define by themselves not only the answers (solutions) but also the questions (re)defining part of the problem posed by the teaching staff or by a company or institution. This would also develop their self-awareness, self-efficacy and critical thinking, as they would question the existing problem and allowing redefining to some extent the briefing from the teaching team, we would be encouraging them to lead their own projects. On a broader level, if instead of having an industry problem to solve with a clear briefing from a company or institution, they have an open-ended problem and they need to find the problem, and if the possibility or just the idea of them creating a theoretical startup to market the solution is allowed, they would not only be developing the aforementioned skills but also, they would develop their entrepreneurship abilities.

To minimize the Dunning Kruger effect observed in some areas of knowledge that are not core to the engineering body of knowledge, it would be recommended to raise the awareness in the students by the teaching staff related to the topic under discussion. When teaching some content that is not covered in depth or to all its extent that is not within the core of engineering skills, students must be aware of the limitations of what they are learning and the vast knowledge available within that specific field. Thus, they can better judge their level of knowledge or capacities related to that field in the future. Examples of this are creativity, user research, sustainability among others, which might be covered or slightly mentioned. If not treated correctly, this might lead them to think they know enough just because they heard it on a class. Of course, it's good for them to know these topics, but is good also that they know that there is way more, and that there are specific professionals also dedicated to these areas of knowledge. In that way, in their future professional lives they would be able to make better risk management, decisions and judgment when facing situations involving topics they've learnt but they didn't master to all its extent.

Regarding further research in how to better develop innovation competences in engineering students, to better understand in depth which competences are being develop and the acquired knowledge by the students vs. their prior knowledge it is recommended to implement a pre-test and post-test experiment. It could be done by using the INCODE Barometer survey to measure their self-perception before taking the courses and after taking the courses to evaluate afterwards the increase or decrease in innovation competences. Also, it would be recommended to combine this type of survey with a qualitative methodology. This could be either content analysis of, for example, an essay of what is innovation, or interviews with the students before and after taking the course or project results. This pre-test and post-test experiment would be very beneficial to better design the courses and adapt the contents to better develop innovation competences in engineering students. Also, to have clear metrics on students experience or satisfaction with the courses, it would be recommended to have an indicator like the NPS (Net Promoter Score) for each course, rating the experience right after finishing the course. If possible, the NPS would be recommended to have across other courses beyond PDP and CBI, to have a comparison within the UPC courses and also it is recommended to have the NPS for CBI students from ESADE and IED.

Chapter 6 - Activities and publications

Teaching

- The author of this work participated since 2014 (first edition) to 2019 in the conceptualization, design and implementation of the CBI course, as a coach and teacher of Design Thinking and user-centric innovation.
- On a weekly basis, coaching and teaching sessions were carried out with the teams to help and guide them through the development of the projects.
- Also accompanied students to the periods of time at CERN to engage and interact with researchers and at the end to present their projects to the CERN community.
- Other education / teaching activities were carried out in parallel by the author at IED (Coordinator of the Masters in Design Strategy, Innovation & Entrepreneurship) and at ESADE (Director of the Innovation Lab at the Full Time MBA), among others.

External support & feedback

- In March 2018, research project was reviewed with Katerina Bagiati, Research scientist within MIT Office of Digital Learning, expert in qualitative research.

- In September 2018, when participating in the SEFI Doctoral Symposium, research project was reviewed, and feedback was received from experts in engineering education:
    - Wim Van Petegem, Professor at KU Leuven, expert in Engineering Education with focus in innovation (among others) and former president of SEFI innovation.
    - Cynthia Finelli, expert in engineering education and founding Director of the Center for Research and Learning in Engineering at the University of Michigan

Conference's participation & communications

Two communications to congresses have been made as first author during the Doctorate Program, one of them indexed in the IEEE Explore database. Also, a conference communication in which the author of this thesis was co-author was performed before the formal admission in the Doctorate Program. The communications are included in the Annex A of this thesis.

- Congress: *4th International Conference on Higher Education Advances (HEAd'18), Valencia, España, 20-22nd June 2018*
  Title: *Education for innovation: engineering, management and design multidisciplinary teams of students tackling complex societal problems through Design Thinking*
  Authors: *Charosky, Guido; Hassi, Lotta; Leveratto, Luciana; Papageorgiou, Kyriaki; Ramos, Juan; Bragos, Ramon*

- Congress: *XIII Technologies Applied to Electronics Teaching Conference (TAEE), 2018, Tenerife, España, 20-22nd June 2018*
  Title: *Challenge based education: an approach to innovation through multidisciplinary teams of students using Design Thinking*
  Authors: *Charosky, Guido; Hassi, Lotta; Leveratto, Luciana; Papageorgiou, Kyriaki; Ramos, Juan; Bragos, Ramon*

  Link to IEEE Explore: https://ieeexplore.ieee.org/document/8476051

- Conference: *Proceedings of the 12th International CDIO Conference, Turku University of Applied Sciences, Turku, Finland, June 12-16, 2016*
  Title: *Mixing Design, Management and Engineering Students in Challenge-Based Projects*
  Authors: *Hassi, L., Ramos-Castro, J., Leveratto, L., Kurikka, J. J., Charosky, G., Utriainen, T. M., Bragos, R., Nordberg, M.*

Journal articles publications

One article has been published in the International Journal of Engineering Education (2021). The International Journal of Engineering Education (IJEE) is in the quartile Q1 (Engineering-miscellaneous, 2020) and in Q2 (Education, 2020) according to SJR (Scimago), and in Q4 (Engineering-Multidisciplinary, 2020) and in Education - Scientific Disciplines (2020) according to JCR.

Another article has been accepted (publication pending in 2021) in the European Journal of Engineering Education. The European Journal of Engineering Education (EJEE) is in the quartile Q1 (Engineering-miscellaneous, 2020) and in Q2 (Education, 2020) according to SJR (Scimago), and in Q2 (Education and Educational Research, 2020) according to JCR.

A third article has been published in 2021 in the CERN IdeaSquare Journal of Experimental Innovation (CIJ). This Journal is in the quartile Q4 for Information Systems and Management (2020) and quartile Q4 for Management of Technology and Innovation (2020) according to SJR (Scimago). This journal is indexed in DOAJ and in SCOPUS. It is a newly created online journal that is still not listed in JCR.

The data of impact factor from https://www.scimagojr.com/ and https://jcr.clarivate.com/jcr/home

The articles are included in the Annex B of this thesis.

- Published article:
  - International Journal of Engineering Education Vol. 37, No. 2, pp. 461–470, 2021
  - Title: Investigating Students' Self-Perception of Innovation Competences in Challenge-Based and Product Development Courses
  - Authors: Charosky, Guido and Bragos, Ramon

- Accepted Article (11th August 2021) / DOI 10.1080/03043797.2021.1968347 / Pending publication
  - European Journal of Engineering Education
  - Title: Developing Innovation Competences in Engineering Students: A Comparison of Two Approaches
  - Authors: Charosky, Guido; Hassi, Lotta; Papageorgiou, Kyriaki; Bragós, Ramon

- Published Article:
  - CERN IdeaSquare Journal of Experimental Innovation, 2021; 5(1): 5-10
    Special Issue: "Inspiring the future change-makers: reflections and ways forward from the Challenge-Based Innovation experiment".

DOI: https://doi.org/10.23726/cij.2021.1290

- Title: Prototyping the Future of Learning: Reflections from Seven Editions of Challenge-Based Innovation (2014-2020)
- Authors: Papageorgiou, Kyriaki; Bragos, Ramon; Charosky, Guido; Hassi, Lotta; Leveratto Luciana; Ramos-Castro Juan

- Article under development:
  - A new work is being prepared about the study of the correlation between the bachelor access mark and the project/non-project courses

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Annex A – Congresses communications

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Challenge based education: an approach to innovation through multidisciplinary teams of students using Design Thinking

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***Abstract*— This work aims to describe and discuss the benefits and learning outcomes detected along four iterations of a learning experience carried out by three institutions: ESADE Business School, IED Istituto Europeo di Design and the Telecom Engineering School of UPC, Universitat Politècnica de Catalunya. Mixed teams of students from the three institutions face open innovation challenges with societal interest through Design Thinking. This study is focused on the learning outcomes of engineering students, compared to the ones obtained by Telecom engineering students that follow standard project-based courses. The students spend 3-4 weeks at IdeaSquare, a creative environment created at CERN Meyrin site in Switzerland, where they can consult and interact with scientists and knowledge transfer experts about possible applications and uses of CERN technologies in the student's proposed solutions. One example of a prototyped solution is a low-cost sensor-based system to detect malfunction in water wells in Africa, which uses SMS-based communication and cloud-based solutions to manage wells repairs. As a result, the ICT engineering students increase their awareness of user needs and the relevance of the problems to focus on when tackling a complex challenge. They also increase their ability to ideate more disruptive and high-impact solutions thanks to their understanding of the "big picture" based on their interactions with design and business students.**

***Keywords*— challenge based education; multidisciplinary teams; design thinking; innovation**

I. Introduction

Innovation is not only about technology or technical solutions to problems, either business, market or industry based. Innovation is about solving complex challenges and developing solutions to these challenges tackling them from three perspectives: business, technology and people.

Every discipline involved in the innovation process is fundamental and a deep knowledge in engineering (technology), management (business) and design (people) is needed to develop solutions that have greater chances to succeed in the market.

As a society we are facing extremely complex challenges today and in the near future like water scarcity, climate change, over population, immigration and refugees, among others. To tackle this type of challenges, solutions must be holistic and the approach must be in multiple directions.

Training future professionals in the processes and methods to innovate and in understanding how to tackle this type of challenges from a multidisciplinary perspective could increase the chances to have solutions with greater chances to succeed.

For engineering students, getting to understand the innovation process, working in multidisciplinary teams with management and design students and approaching solutions beyond the purely technical or engineering perspective makes a great difference in their learning experience.

These types of complex challenges pose unforeseeable uncertainty [1] and require different approaches than "traditional" engineering projects. Design Thinking is a human centric innovation approach to innovation [2] suitable to deal with uncertainty in the early phases of projects through in depth user research, ideation and early prototyping and testing of solutions in an iterative process.

Based on Dym's research [3] using Design Thinking in project-based learning is the best pedagogical model for teaching design.

Challenge Based Innovation (CBI) is a program created by CERN to host educational projects where students from different disciplines working in multidisciplinary teams tackle innovation challenges through Design Thinking. The objective is to design solutions to complex social problems, considering the use of CERN technologies if suitable.

The objective of this paper is to describe the process, methodology and learning outcomes (focusing on engineering students) and examples of the technical solutions and prototypes as result of this new educational experience carried out by three higher education institutions: UPC (Telecom and Computer Science students), the business school ESADE and the Barcelona site of IED, Istituto Europeo di Design, after four editions of this course.

The methods and results are compared with the ones developed by a more classical approach: the capstone project that is carried out in the fourth year of the Telecom Engineering degree. In this case, challenges are also stated by external companies or institutions but are basically technical challenges, which have initial requirements and even specifications.

II. Design Thinking

According to Tim Brown, "Design thinking is a human-centered approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success" [2].

In the past decade, Design Thinking arisen as an innovation methodology to tackle complex problems, also beyond business or commercial environments. It is not a new phenomenon, as design professionals have been working with this processes and methods for many decades. What is rather new is using Design Thinking as a universal tool for problem solving and innovation in other fields than design, like management.

This approach brings together and balances what it is desirable (what people needs), viable (economically sustainable from the business point of view) and feasible (from the technology perspective).

The principles of Design Thinking are: Human-Centered, Collaborative, Iterative, Holistic and Experiential.

These principles emphasize the observation of people behaviors to detect needs and opportunities, collaboration in multidisciplinary teams, early visualization and rapid prototyping of ideas and solutions and testing in an iterative process. It does not replace professional design or engineering. It is a methodology for early stages of the innovation funnel [4].

Within the Design Thinking process we can clearly identify two different "spaces" to explore: the problem space and the solution space. Within the problem space, the focus is placed in understanding the challenge, the context, the user/s and stakeholders and detecting needs to be solved and opportunities. In the solution space, the aim is to generate multiple ideas and solutions to the specific needs and opportunities identified in the previous phase. These solutions are then prototyped and tested in an iterative process to learn and improve before developing the final solution.

From the cognitive perspective, it combines divergence and convergence processes to generate several choices and only then make choices between the alternative options [2].

According to [5] it is a process composed of 6 iterative phases where back and forth movements are involved between the different phases (Figure 1)

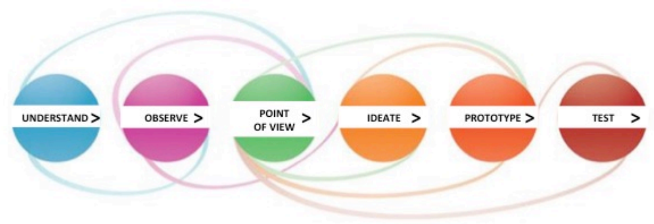

Fig. 1. Steps in a Design Thinking process . Adapted from [5].

The six phases are Understand, Observe, Point of View, Ideate, Prototype and Test. The first three phases belong to the problem space and the last three to the solution space. They will be developed through an example in section V.

III. Challenge Based Innovation (CBI) at CERN

A. *IdeaSquare @ CERN*

The European Organization for Nuclear Research, CERN, is dedicated to fundamental research in particle physics since 1954. According to CERN website "physicists and engineers are probing the fundamental structure of the universe. They use the world's largest and most complex scientific instruments to study the basic constituents of matter – the fundamental particles". In order to do this, they develop very specific and complex technologies. These technologies are purpose-built particle accelerators and detectors, which are instruments scientists use to observe and record the results of their experiments (collisions of particles).

More than 12.000 scientists from all over the world collaborate with CERN in these scientific experiments and developing new hardware and software. The technologies they develop for their experiments could have great potential applications and impact in the society. Some of them even can change our lives, like the case of the World Wide Web, invented by Tim Berners-Lee in 1989 at CERN. To find ways to allow, facilitate or accelerate the process of discovering societal applications for CERN technologies, a new experiment called IdeaSquare was created in 2013 in collaboration with Aalto Design Factory, which is a multidisciplinary teaching and development unit from Aalto University.

The objective of IdeaSquare is to prove or demonstrate that applying fundamental research concepts to tackle societal challenges is of value. For this purpose, IdeaSquare hosts different activities: long-term research projects on detector R&D, different innovation-related events and hackatons and multidisciplinary university projects like CBI (Challenge Based Innovation) [6]. Challenge Based Innovation is a human-centric experimental project hosted by IdeaSquare where multidisciplinary teams of students tackle societal challenges. Within these wide challenges, they identify end-user needs to be addressed. In collaboration with CERN mentors and coaches from their home Universities, they ideate and create tangible prototypes of the solutions inspired in relevant novel technologies from CERN.

To achieve better synergies and connections with CERN all student teams have a CERN mentor who helps them and guides them in everything related to technologies from this research institution. Also, the students have weekly working sessions with their coaches from their home institutions to progress in their projects.

B. CBI Course Structure

Similar to the four phases of the Double Diamond design process from the Design Council [7], which is based in the Design Thinking methodology, the basic structure of CBI is composed of three main blocks: Discover, Design and Deliver.

In the initial Discover phase, the teams focus on deep diving into their challenges, understanding the context, trends, benchmarking, needfinding, doing basic research and user research (observation, interviews, etc). At the end of this phase the teams define the specific need or problem they are going to tackle within the original challenge. In the Design phase the students generate multiple ideas and solutions to the problem that are prototyped in low resolution (cardboard, paper, etc) to quickly iterate and learn through user testing. After these iterations, one solution is chosen to be further developed and prototyped with higher resolution. In the Delivery phase, the selected idea is prototyped to a proof of concept level and the solution is developed from the technical, design and business model perspective. At the end of the project, all teams present their solutions and prototypes in a gala event at CERN in front of scientists and universities audience, with media coverage.

Ideally the societal challenges for the course are defined in collaboration with NGOs or companies, and with IdeaSquare team. The topics of the challenges are broad and allow multiple ways to approach them, aiming for educational and learning outcomes rather the technical solutions of the projects. In the two last editions, alignment with UN Sustainable Development Goals (SDG) has been taken into account when defining the challenges.

Teams are usually formed by six students (two from MBA, two from engineering and two from design). In a few cases, some teams had only one representative of one of the institutions. In several cases, they have been added to mixed student teams from other international universities also involved in the Aalto Global Design Factory Network.

The schedule and practical arrangements of the course has been adapted year by year. The course itself is a prototype. In the current setup, there is a kick-off period, with an initial intensive week in one of the local institutions followed by a 3-5 days at IdeaSquare@CERN. Then, there is a weekly full day (8 hours) devoted to the projects in one of the local institutions along 5 weeks, followed by an intensive week 3-5 days at IdeaSquare@CERN where the ideation phase is finished in most cases. Then another set of 5 weekly days at one of the local institutions, devoted to converging in one solution and designing it and a final intensive period of 10 days at IdeaSquare@CERN for solution integration and final presentation.

Each team at the end of the project must deliver the following items:

- Prototype of the solution (proof-of-concept)
- User testing feedback
- Demonstration of the impact of their solution
- Clear description of their link to CERN
- Final project presentation
- Well-documented project and process description
- Project video

According to the CBI Student Guidelines document, shared by the three institutions, the course learning outcomes are:

- Develop an Advanced Design project applying a methodology focused in product innovation.
- Study and guide the creation of future scenarios, based on a deep analysis of present and past, with the aim of creating new ideas applicable to the new context.
- Analyze the project considering market, society and technology, to define clear areas for new opportunities.
- Achieve the proper presentation tools to present and explain the design process, both orally and in digital format.
- Apply a strategy, making decisions for achieving innovation and quality.
- Fundament the concepts in a multidisciplinary project from a theoretical and practical perspective.

- Present and represent design ideas applying the proper techniques.
- Apply the proper digital technology for the communication and presentation of projects.
- Implement specific design research and experimentation techniques.
- Find out and study the productive processes for the fabrication of the designed projects.

The assessment of the individual students is based in the team performance (50%), the individual performance (35%) and the peer assessment (15%). The first two marks include several aspects specified in a rubric. Taking into account that the teams have, at least, a weekly coaching hour with several faculty members, we can use authentic assessment.

Feedback about the course is obtained through a specific feedback session with all students and faculty members, an individual reflection document and several questionnaires supplied by the different institutions.

IV. Capstone project at the Telecom Engineering School

For the sake of comparison with the CBI course, the capstone project, which is performed in the fourth year at the Telecom Engineering School, will be briefly described. When designing the engineering degree curricula according to the EHEA directives, the Telecom Engineering School adopted the CDIO Standards [8] and, as part of the implementation of the CDIO model, included a project courses path which currently includes a project-based course in the second, third and fourth year of the bachelor. The projects' complexity and degrees of freedom grow along the three iterations and also the team size increases. The capstone project, called Advanced Engineering Project (AEP), is located at the first term of the fourth year and has 12 ECTS credits. Teams of 7-12 students face a complex challenge by splitting in sub-teams, designing and implementing the different parts of the project and finally integrating ant testing the product, process or service, including the definition of a business plan. The teams usually have a mixed composition of students from the different minors of the Telecom Engineering degree (Electronics, Networks, Audiovisual Systems and Communication Systems). This subject has also evolved along the eleven iterations that already occurred. Currently, 8-10 different challenges are offered every semester. 7-8 out of 10 are proposed by companies or external institutions (hospitals, NGOs, …) and 2-3 are proposed by research groups. The projects follow a more classical structure: starting by requirements and even specifications to solve a technical need identified by the stakeholders, the teams build a Project Charter document and a Project Management Plan, following the PMBOK standard, and get them approved by the faculty members and the external advisors. Then they execute the different work packages they have defined until a Critical Design Review approximately located in the 8th week and then continue with the updated project plan until presenting the product or service and delivering the Final Report at the end of the semester (13-15 weeks).

The assessment of the individual performance is obtained by giving an overall mark to every project, which takes into account the different aspects and deliverables (technical performance and complexity, innovation, prototype, reports and presentation). This overall mark is modulated for every individual student with three factors: supervisors' individual assessment, team leader assessment and peer assessment performed by the team peers using a rubric, with a weight of 30% each. The feedback is collected through a reflection document included in the Final Report.

V. CBI and Capstone project examples

Along the 4 editions of the CBI course in which our three institutions have participated, 18 different projects have been carried out, four in the first two years and five the last two years. As examples of the stated challenges:

- How can we design a viable system that allows people to restore or enhance their ability to move?
- How might we improve public health by providing safe access to water?
- How might we deliver food to homes in a new way that maintains the food cold at a selected temperature, ensuring its safety?
- How might we improve the cognitive development and communication skills, and consequently the quality of life, of people with Intellectual and Developmental Disabilities through ICT?
- How could technology help to improve the living conditions of refugees, displaced and other people in need of emergency temporary sheltering?
- How to use new technologies to revamp radiation inspection methods?
- How might we use immersive technologies to design realistic, productive and memorable learning experiences for humanitarian missions in risky environments?

To give an overview of how the projects were developed according with the Design Thinking methodology, we give more details on two of them. About the challenge "How might we improve public health by providing safe access to water?", the six students team explored the needs in the sub-Saharan region through local and remote contacts at NGOs and international agencies. They focused in rural areas in Ghana and first explored the needs: locating water sources, sanitizing the water, improving the safety of the water use, … Then they explored the feasibility of using CERN-derived technologies:

high efficiency solar collectors for disinfecting water, using advanced sensors to perform remote sensing of water sources, advanced filtering devices … In all cases, they shared their findings with the stakeholders. At the end, and through the stakeholders' feedback, they realized that the main problem in this area was not the scarcity of water wells but the fact that more than 70% of wells were out of function. They also found pitfalls in the way the money provided by NGOs was used. The solution they designed (figure 2) and prototyped (figure 3) was a low-cost sensor arrangement that was attached to the well outlet pipe (no need of modifying it), detected if the well was operated through vibration pattern detection, if water was flowing through temperature change detection, and sent an SMS message to a cloud-server that displayed the well status in a synoptic map in the nearby villages and activated a Uber-like network of potential repairers, who would be paid through a NGO when the correct well status was automatically checked. The solution, at the end, only used the C2MON cloud solution from CERN technologies but potentially solved a relevant problem.

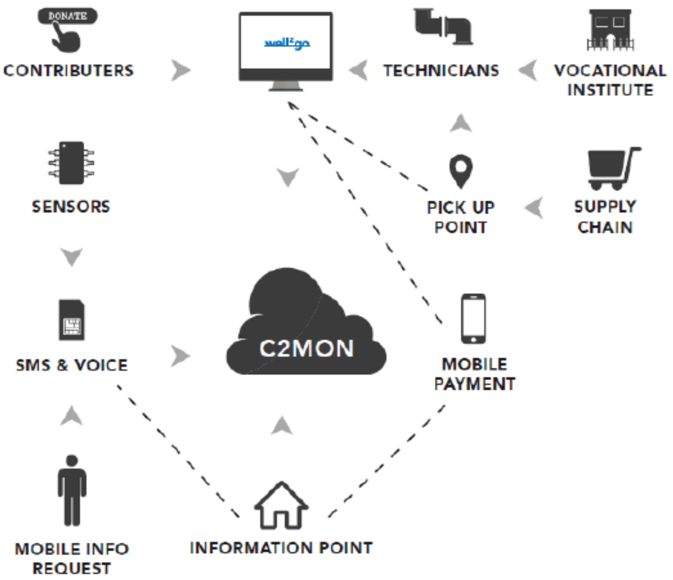

Fig. 2. Block diagram of Well2go, the system designed in the CBI course (2015) to improve the safe use of water in Ghana

Fig. 3. Prototype of the Well2go system

The second of the chosen examples is the challenge "How to use new technologies to revamp radiation inspection methods?". In that case, the students interviewed the CERN experts in radiation inspection, staff at a nuclear plant, managers of radiation therapy facilities in hospitals, public-health officers at the City-Hall, … The conclusion of the research phase was that the highly standardized radiation inspection procedures, although could benefit from an appealing revamp through the use of new technologies (e.g. augmented reality), were a field that affected few people, and that people had strong technical skills and did not really need more comfortable methods which, on the other hand, would find difficulties to be approved by the regulation agencies. In opposition, they found through CERN contacts that there was a radiation-induced problem with high impact in the population due to the accumulated exposition to radon gas in houses and workplaces with low ventilation, which results in a number of lung cancer cases. The students designed and partially prototyped a solution based on radon sensors developed at CERN which also included a service build on top of a database and a smartphone app which calculates and displays the accumulated exposure of an individual to radon gas using sensors and publicly available information and also takes into account the individual susceptibility based on family history of lung cancer and other environmental factors (smoking, …) and that could include genetic data in the future.

Almost all challenges and solutions have a similar story of choosing the relevant need and solution through intense user feedback although the solution was not so appealing from the technological point of view. The final reports and videos of the projects can be found at http://www.cbi-course.com/, under the "Projects" section.

While 10 students per year get their 12 ECTS credits of Advanced Engineering Project through the CBI course, only in the fall term, the remaining 160-200 students per year do it in the regular way through one of the 8-10 capstone projects (AEP) proposed every semester. Up to 78 projects have been carried out up to now. Most of them are new every semester and a few (one-two per semester) may be a continuation or second version of a previous one. A few examples of the kind of topics stated by the stakeholders are the following:

- Software application based on image and video processing to aid the rehabilitation of facial paralysis after facial nerve injury.
- Portable, non-destructive testing equipment to determine the health of "trencadís" tiles of Sagrada Familia temple.
- Improvement of several features in large-format printer sensors
- 3Cat-NXT and Distributed Satellite System projects: successive developments around a Cube-Sat platform
- Cost Effective communication payloads in Stratospheric Balloons

- Localization and monitoring of workers and assets in a Digital Factory indoor environment.
- Automatic analysis of infant sleep structure
- Chatbot for banking user-interface
- Low-cost, robust, autonomous blood-pressure measurement system for developing areas.
- Use of radar for non-contact measurement of ventilation and heart rate in newborns.
- Explore technologies for human-machine interface in vehicles.

In almost all cases, there is an initial statement which points directly to a technical solution, although the initial requirements are a bit open (we ask the stakeholders to do so), and it is a task of the students to explore the client needs around the product and define specifications that have to be agreed with the stakeholders. Nevertheless, in all cases, the need is already identified and in most cases there are clear clues about the technical solution. All projects should have complexity in order to allow splitting them in 3-4 parallel work packages (hardware, firmware, data processing, application and user-interface software, …) and solutions using advanced techniques and high level of abstraction are encouraged. At the end, the students develop a prototype able to perform a demonstration of the developed concept, including a business plan if the result is a product or service or at least the analysis of the engineering costs if it is an internal subsystem. For example, the challenge of detecting the adhesion state of "La Sagrada Familia" tiles (figure 4) resulted in a solution that involved:

- Image processing to identify the individual tiles from a picture taken with a tablet (image segmentation).
- A knocking device to test the tiles and a microphone and an acquisition system to record the resulting sound (based on a Raspberry Pi).
- A signal processing algorithm to distinguish the tiles that are well adhered from those that are not.
- A user interface that allows displaying the tiles which are not well adhered in a user-friendly way.
- A test campaign with reference samples.
- A business model about the possible commercialization of the product for additional uses.

Almost all projects involve a strong technical workload, with the design of several intermediate prototypes including the use of prototyping platforms (development boards, 3D printing, software development frameworks) and accurate treatment of measured data. In the last editions of the course, more than half of the projects proposed by external companies have solutions based only in software, with prevalence of data analytics, machine learning and BlockChain. Also the students' preferences are shifting to these fields.

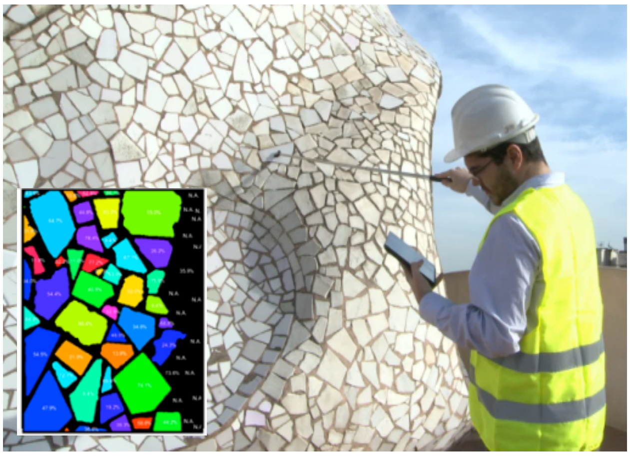

Fig. 4. System to detect adherence of tiles, developed in the AEP course.

VI. CBI AND CAPSTONE PROJECTS COMPARISON

Both types of projects can be compared according to several criteria:

- About the context, in both cases the course provides a context close to a real-world activity and is therefore more suitable to obtain deep learning outcomes than regular theory-lab-problems-exam subjects. There are, however, some differences. In the capstone projects, the context is known and the multidisciplinarity is limited to the different minors into ICT engineering disciplines. On the other hand, in CBI, the context is unknown; all the students (mainly the engineers) are out of their comfort zone and have to learn to work with others.
- About the technical complexity and deepness, as it was said in the previous section, in capstone projects is high and there are strong learning outcomes on the science and technology involved in the solution, although this is not the main goal of the subject. In the CBI course, due to the lower workload devoted to the technical solution (less time, only 2 engineers per team), the complexity and deepness are lower, although relevant. The goal is to provide a final prototype able to provide a proof-of-concept of the critical parts of the solution.
- About the user-needs awareness, in the capstone course is usually low, with some exceptions. Although this aspect has improved since we have external stakeholders for almost all projects, the specifiers are usually engineers and not final customers, and the projects often are technology-driven. In the CBI course, the user awareness is extremely high, and so is the potential innovative impact of results, while the technology takes a secondary role. There is an issue that we have learnt that has to be controlled: Engineering students tend to apply technological solutions in the low-resolution prototyping phases during needfinding and ideation, where they are still

not needed and could distort the user-approach. Also the engineering students (and even the teachers) use to reveal the technology limitations in the ideation phase, where disruptive solutions that go beyond the currently possible solutions could appear.

- About the project planning and documentation, it follows a strict protocol in the capstone projects, using an adapted version of LIPS [9] and PMBOK [10] models. Although it is presented to the students as a way of ensuring the project success, it is often seen as bureaucracy and as an obligation. In creative processes, like the CBI course, however, documentation and planning are not so strict and are mostly based on presentations, videos and low-resolution prototypes, with a lot more iteration and interaction with users than the classic projects. The method can be considered close to the extreme-agile software development method.

- In capstone projects, the students feel stress on the need of completing the assigned sub-system on time and on dealing with incidences. In the CBI projects, the stress is put in the first two thirds of the course in the collaborative sense making (all students from all disciplines participating in all phases) and only in the last third, on the delivery of specialized outcomes.

- About the quality of the results, all these subjects are highly motivating and the project results are usually good or very good, often outstanding. In the capstone project, the students' commitment is medium to high and there are only a very few cases every year of individual students not getting good results and marks, even failing the subject. In the CBI course, the results are usually outstanding. There is a bias factor in the fact that the students compete to be part of this course and some of the best ones are chosen, but there is in any case a very high commitment and also the pressure of presenting at CERN. Also in the capstone projects proposed by external institutions the pressure and commitment are high, while in capstone projects proposed by faculty members, the students feel that are among peers and the context is closer to a regular subject.

VII. Conclusions

The true-multidisciplinary structure of teams has been identified as the highest value of CBI course, above the international experience and the singular environment of CERN and the possibility of contacting high-level scientists and technologies.

The inclusion of intensive periods in singular workspaces, out of the regular classrooms and labs has also been identified as a key factor for success.

The Design Thinking approach provides powerful tools to deal with uncertainty in open challenges, thanks to the systematic way to tackle it through iterative divergent-convergent phases and the test with users and other stakeholders.

This multidisciplinary experience has shown to be a successful tool to enhance the innovation and entrepreneurial skills in engineering students. Due to its cost, it cannot be scaled to all the students, but the methods developed and lessons learnt can be partially applied to capstone projects and even to standard courses.

Not all engineering students are prone to become entrepreneurs. The goal is to identify these who are through the exposition to CBI-like experiences and provide them experiences to enhance the innovation and entrepreneurial skills. The (not so) standard capstone projects would provide tools to get the learning outcomes of analytical design. There is a tradeoff: the direct contact with users improves the creative part (needfinding, ideation) but reduces the time for designing complex solutions and the associated learning outcomes. Then, with limited time and resources, engineering students should choose between acquiring more entrepreneurial skills or more technical skills.

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Education for innovation: engineering, management and design multidisciplinary teams of students tackling complex societal problems through Design Thinking

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Abstract

Innovation education involves a different approach both for professors and students. It requires understanding people, technology and business to develop truly innovative solutions that can succeed in the market.

The aim of this paper is to analyze the benefits, learning outcomes and self-learning perception about innovation from students participating in an innovative learning experience co-developed by an Electrical Engineering School, a Business School and a Design Institute.

Challenge Based Innovation (CBI) is a program created by CERN to host educational projects where multidisciplinary teams of students tackle innovation challenges. The objective is to design solutions to social problems through Design Thinking.

It was observed that engineering students, after this learning experience increase their understanding of user's needs and the relevance of focusing on them when approaching innovation challenges. Also, they improve their ability to ideate break-through solutions thanks to a better understanding of the relationship between people, business and technology due to their in-depth interaction with management and design students. Furthermore, their self-confidence is significantly increased along with their entrepreneurial skills.

The level of engineering student's understating of innovation as a whole is higher with this approach compared to standard design-build projects performed at the Engineering Schools.

Keywords: *Design Thinking, Innovation, Challenge Based Education, Multidisciplinary projects*

1. Introduction

The understanding of the design process is important both to manage the design activity and to aid the improvement of products and the overall efficiency of engineering based companies (Howard, Culley, Dekoninck, 2008). It is also fundamental to tackle innovation challenges and to minimize uncertainty during the innovation process. It is also important for engineering students to understand the overall process and going beyond the purely engineering skills or activities.

Originally developed at the Massachusetts Institute of Technology, the CDIO framework (Crawley et al. 2014), defines 4 phases for the product development cycle: Conceive, Design, Implement and Operate.

The Conceive stage includes defining customer needs, understanding technology, company strategy, and regulations and developing conceptual, technical, and business plans. Nevertheless, the emphasis of the Syllabus section 4 of the CDIO Syllabus 2.0 is mainly in the “Design”. Also, most engineering schools curricula focuses on this phase, generally starting projects from requirements or even directly from specifications (Hassi et al., 2016). In the professional world, also is often assumed that engineers need another agent to state the requirements (design, marketing, management…).

Although engineering students feel comfortable with this approach, it limits the capabilities of graduated engineers on influencing on strategy and concept definition for new products and services.

In the past years, new approaches to innovation like Co-Creation and Design Thinking (Brown, 2008) have arisen as methodologies to dealing with uncertainty involved in the “Conceive” phase of any innovation project. Some references can be found about this approach (Yang et al., 2014) (Ping et al., 2011).

According to Dym et al. 2005, the currently most-favored pedagogical model for teaching design is project-based learning (PBL), using Design Thinking.

The aim of this work is to describe and discuss the benefits and learning outcomes detected along four iterations of a multidisciplinary challenge based learning experience carried out by three institutions from Barcelona: an Engineering School, a Design School and a Business School. This study is focused on the Engineering students.

2. Design Thinking

Searching for new ideas and innovative solutions to complex problems (either business, social, educational or others) it is inheritably uncertain and has less certain outcomes than the improvement of existing solutions. Innovation is uncertain by definition.

At the outset of an exploration project, there is neither a clear predefined target, nor a known route to achieve it, certainly no requirements nor specifications. In opposition, classical engineering student projects or even modern engineering capstone projects often start from requirements or even directly from specifications provided by an external or internal stakeholder (Hoffman, 2014).

Design Thinking is an approach to innovation that helps to deal with uncertainty, understanding user needs, exploring solutions and ideas, and validating them through an iterative rough and quick prototyping process. It is a human-centered methodology that uses the tools and methods from the design disciplines and it is recognized for its clear bias towards abductive and integrative thinking, exploration and visualization. According to Rattcliffe (2009), the Design Thinking process can be separated in two clear “spaces”: the problem space and the solution space. From the cognitive perspective, it is a divergent and convergent process combined, where a set of alternatives are created and only then, choices are made based between the different options (Brown, 2009). It is a process composed of six iterative phases involving back-and-forth movements between the phases in a non-linear way (Figure 1). The phases are Understand, Observe, Point of view, Ideate, Prototype and Test.

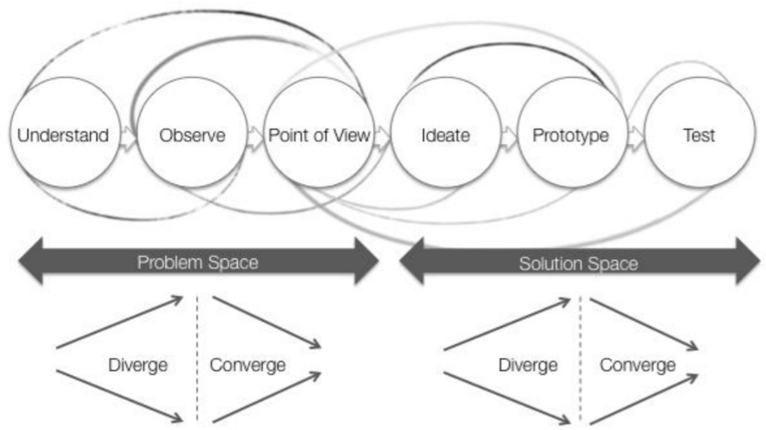

Figure 1. Adapted from Rattcliffe (2009)

3. Mixing engineering, design and management students at CERN to solve social challenges

Challenge Based Innovation (CBI) is a program created by CERN, the European Organization for Nuclear Research, to host educational projects in which students from different disciplines, universities and nationalities are put together in multidisciplinary teams to tackle innovation challenges. The objective for the students is to design solutions to social problems through the innovation methodology called Design Thinking.

During one semester the students spend 3-4 weeks at IdeaSquare (http://ideasquare.web.cern.ch/), a creative environment created at CERN Meryin site in Switzerland, where they can consult and interact with scientists and knowledge transfer experts about possible applications and uses of CERN technologies in the student's proposed solutions.

Management, Design and Engineering schools usually perform project or case based courses about product or service development, but the fulfillment of the aforementioned design phases gains a lot of added value if the three agents of the process participate simultaneously on it because they cover the three key aspects: economic viability, usability/desirability and technical feasibility. The three institutions started performing shared activities four years ago, being the most relevant one the one that is performed in collaboration with IdeaSquare at CERN.

Together with IdeasSquare staff and mentors and faculty from the three different universities, teams draw inspiration from relevant novel technologies and create tangible prototypes. In three out of four editions, the teams have also included students from universities of other countries.

The basic structure of CBI course is divided into three parts: Discover, Design and Deliver (Design Council, 2005). In the Discovery phase, the student teams deep dive into their societal challenges, seeking to understand the "big picture" and in depth user needs. The phase ends with a clear statement and specific need or problem to address within its challenge. In the Design phase, the teams create quick and rough prototypes of the solutions for the needs they have discovered and then they test with users to get feedback. They choose one of the concepts and in the Delivery phase, this concept is developed including a functional, proof-of- concept prototype. At the end, the results are presented in a gala at CERN.

Some examples of the challenges tackled in CBI are: allowing people to restore or enhance their ability to move, providing a way for safe and fair distribution of electric power in refugees' camps or improving the water usage in developing countries.

A risk of this kind of multidisciplinary activities is the possibility that the students of a given discipline remain in their silo and only develop skills related with their previous knowledge. This is avoided by a course time plan, which drives all the students through all the design phases by doing collaborative activities, often taking them out of their comfort zone. There are also short lectures on key disciplines aspects oriented to all the students. Only in the last step (final proof-of-concept prototype) the engineering students devote more time to the technical development, the business students to the business plan and the design students to the graphical and communication aspects of the final presentation, reports and video, but even in this last phase the cooperation is intense thanks to the fact of being performed in a 10 days intensive period.

4. Challenge-based learning

According to Malmqvist et al. (2015) a challenge-based learning experience "is a learning experience where the learning takes places through the identification, analysis and design of a solution to a sociotechnical problem. It is typically multidisciplinary, takes place in an international context and aims to find a solution, which is environmentally, socially and economically sustainable."

It could be said that challenge-based learning is an evolution of problem-based learning, with a more holistic approach. In problem-based learning, students are required to tackle a a design, research or technical problem and their learning occurs in the process of working on the solution, normally in teams with the same or similar skills (i.e. engineering students).

Challenge-based learning experiences are more complex but more enriching, as they expose the students to work in multidisciplinary teams, and to address more complex societal challenges. These challenges combine not only the societal goals and the technical solutions, but also the business development or business model required to tackle them.

In this multidisciplinarity, students get to understand how other disciplines' professionals think, talk, tackle problems, face uncertainty, make decisions,… This type of interactions are extremely beneficial to prepare engineers to manage real life innovation challenges, where multidisciplinarity is mandatory and understanding "the big picture" and understaning the needs and objectives of all stakeholders is fundamental.

The evolution from problem-based learning to challenge based learning in engineering education is illustrated in Table 1, where key aspects of each approach are compared. Main differences are the different disciplines involved in challenge-based (engineering and business) versus only engineering in problem-based. Also, the main activities that go from designing the solution in problem-based to formulating the problem and then designing the solution in challenge-based education.

Table 1. The evolution from problem-based learning to challenge based learning is illustrated in table 1 highlighting key aspects of each approach

	Problem-based	Challenge-based
Disciplines involved	Engineering	Engineering & business
Context	Product context	Societal context
Main activities developed	Designing the solution	Problem formulating & designing the solution
Working model	Team based	Team based and individual
Main focus	Customer needs	Customer needs and societal value creation

Source: Adapted from Malmqvist, Rådberg & Lundqvist (2015)

5. Conclusions and learning outcomes

According to the feedback surveys and personal reflections performed by the students in the four course editions, the most valuable learning outcomes, above the singularity of CERN-related issues and the international experience are the aspects derived from the multidisciplinarity: knowing the way the others think, their tools and methods, being able of giving the right value to the other's work and developing a common language.

As one student mentions about his main take away from the course: "How to work with people from other disciplines, understanding their points of view, in order to come up with the best solution to a problem not only from a technological approach." The understanding of innovation beyond technology and engineering is one of the great achievements of this learning experience when talking about engineering students.

In the specific case of engineering students, in addition to the multidisciplinary values, there is a clear improvement in self-confidence and also a clear increase of user-awareness. Also, they gain a broader understanding of the value delivered by a product or service, on top of the technical functionality.

Regarding innovation, when asked what they understood by innovation before taking this course, reponses are mainly related to creating something new or improving something existing. When asked the same question after the course, there are some similar responses but is significant the appearance of many asnwers regaridng impact on the society , solutions to real needs, finding problems and being able to changing your point of view as you gain more knowledge through research and prototyping.

From the methodological point of view, the students appreciate the intensive periods, although the regular academic year schedule does not have the needed flexibility to perform that kind of activities and the students have to do an extra effort to follow this course.

According to the surveys, engineering students agree that their knowledge on innovation increased significantly after taking the CBI course, as well as their business sense.

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MIXING DESIGN, MANAGEMENT AND ENGINEERING STUDENTS IN CHALLENGE-BASED PROJECTS

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ABSTRACT

The aim of this work is to describe and discuss the benefits and limitations that have been detected along two iterations of a learning experience that has been carried out by three institutions located in Barcelona: Istituto Europeo di Design (IED), ESADE Business School and UPC-Telecom BCN. Design, management and ICT engineering students are mixed together in multidisciplinary teams to face a design challenge along a semester. The framework of these projects is the Challenge Based Innovation (CBI) program, a structure promoted by CERN in which students from different disciplines and countries are challenged to design solutions to social needs following the Design Thinking approach. The international and multidisciplinary teams perform several stays (3-4 weeks in total) at IdeaSquare, a creative environment built at the CERN Meyrin site, in Switzerland, where the students can consult with scientists and knowledge transfer experts about their challenges and about the possible use of CERN technologies in the proposed solutions. They also devote a weekly working day in their home institutions along a semester. The challenges are quite open and, according to the Design Thinking methodology, the students follow several divergence-convergence phases: they devote approximately one third of the time identifying relevant needs into the challenge scope and choosing one of them; another third identifying possible solutions for the chosen need and converging to a single one through low-resolution prototyping and testing. Finally, the last third is spent exploring the business aspects and possible technological implementations of the solution and developing a functional prototype, able to provide a proof of concept of the idea. While the technical complexity of solutions is higher in the standard design-build projects performed at Telecom-BCN, the degree of awareness about the user needs and the ability of developing disruptive and high-impact solutions and of promoting the entrepreneurial skills of the students is higher with this approach.

KEYWORDS

Design Thinking, Multidisciplinary projects, Challenge-based projects, Standards: 5, 7, 8, 9.

INTRODUCTION

“Conceive” is the first of the four phases in the product lifetime defined by the CDIO paradigm. CDIO Standards clearly state that the Conceive stage includes defining customer needs, considering technology, enterprise strategy, and regulations and developing conceptual, technical, and business plans. On the other hand, CDIO Syllabus 2.0 refers to the conception phase taking into account the customer and societal needs in points 4.3.1 (Understanding Needs and Setting Goals), 4.4.2 (The Design Process Phasing and Approaches), 4.4.5 (Multidisciplinary Design) and 4.7.8 (Innovation – the Conception, Design and Introduction of New Goods and Services).

Nevertheless, most points of the Syllabus section 4 and most engineering curricula put more emphasis in “Design” and subsequent phases and students’ projects often start from requirements or even directly from specifications, even if an external stakeholder stated them. This is because usually the interlocutors in the companies that specify the product are also engineers. On the other hand, this allows that projects can reach a high technical complexity and that students would learn how to deal with it.

Product designers and designers from all disciplines devote more time and put more emphasis in the user needs. It is often assumed that engineers need that another agent (product design, marketing, management) states the requirements. Although our students feel comfortable with this role distribution, it limits the capability of graduated engineers on participating in the concept creation.

In the recent years, new terms like Co-Creation or Design-Thinking (DT) have arisen as ways of dealing with the uncertainty involved in the conception phase. A few references can be found in the CDIO knowledge library about this approach, most of them from Singapore Politechnic - (Kim, 2011)(Yang et al., 2014) (Ping et al., 2011) which has included specific courses in their curricula. There are also references in Taajamaa et al. (2014).

Following points describe the DT approach and compare it with the classical analytical design approach, more widespread in engineering education and practice. Then, a learning experience that has been carried out by three institutions located in Barcelona: Istituto Europeo di Design (IED), ESADE Business School and UPC-Telecom BCN in which design, management and ICT engineering students are mixed together in multidisciplinary teams is described. The framework of these projects is the Challenge Based Innovation (CBI) program, a framework developed and promoted by CERN in which students from different disciplines and countries are challenged to design solutions to social needs following the Design Thinking approach. Part of the course is performed at IdeaSquare (http://ideasquare.web.cern.ch/), a creative environment built by Aalto and CERN at the CERN Meyrin site, in Switzerland. The learning outcomes of the engineering students, compared with those obtained in the regular design-built courses at Telecom-BCN, are compared and discussed. The description and outcomes of other challenge-based projects developed in the CDIO environment can be found in (Malmqvist et al., 2015)

DESIGN-THINKING VS ANALYTICAL DESIGN

Design-Thinking - a methodology to guide exploration in innovation

In order to come up with innovative solutions to meet the market needs, a product development team needs to be skilled in exploration. Exploration is fundamental for innovation, and refers to the innovative behavior involved in risk-taking and experimenting with unfamiliar alternatives. This search for new ideas, markets, or relations inevitably faces uncertainty; it has less certain outcomes than the further development of existing ones. (March, 1991, p. 73) At the outset of and exploration project, there is no clear predefined target, nor a known route to achieve it - certainly no requirements nor specifications, while classical engineering student projects often start from requirements or even directly from specifications. Therefore, exploration activities need to be supported by an appropriate methodology that is able to deal with the uncertainty, support the creation of the information required, and flexibly modify the direction of the project as new information becomes available.

Design Thinking is an iterative and human-centered approach to innovation, originating from the design disciplines and drawing from the tools and methods utilized traditionally by designers. This methodology has been credited for its specific support for reflective reframing, integrative thinking, abductive reasoning, and dealing with uncertainty and ambiguity - all conditions for successful exploration (e.g. Hassi and Laakso, 2011 a; Dunne and Martin, 2006; Dym, Agogino, Eris, Frey, & Leifer, 2005). The foundations of DT were laid around the mid 1970's and late 1980's within design research (Hassi and Laakso, 2011 b), focusing on understanding "the way designers think as they work" and drawing from the practice of professional designers, for example architects (Johansson and Woodilla, 2009). While design research keeps building on its broad research history on DT, the concept has gained increasing interest in other fields, such as engineering (e.g. Fai, 2011; Ping, Chow, and Teoh, 2011; Dym et al, 2005) and management (e.g. Kolko 2015; Dunne and Martin, 2006), where it is regarded as a methodology for innovation, problem solving, and value creation. (e.g. Brown, 2009; Johansson and Woodilla, 2009)

There is no single predominant definition for Design Thinking. The notion of Design Thinking is broad and there are even debates over what exactly is meant by it (Cooper, Junginger, & Lockwood, 2009). Following Brown's (2009) description, DT begins with skills designers have used and developed over many decades, while aiming to match human needs with available technical resources, and within the practical constraints of business. The tools from the "designers toolking" are put into the hands of people who are not professional designers, and they are being applied to a vast range of problems. (Brown, 2009, p. 4) DT is essentially a human-centered innovation process that emphasizes observation, collaboration, fast learning, visualization of ideas, rapid concept prototyping and concurrent business analysis. It is not a substitute for professional design, but rather a methodology for innovation in the early stages of the innovation funnel. (Lockwood, 2010, p. xi)

Despite the lack of a consensual definition for Design Thinking, the definitions seem to have some key tenets in common, such as, human-centricity, rough prototyping, iterative knowledge creation, and reflection (Hassi and Laakso, 2011 a; Lockwood, 2010 p. xi). Perhaps the most prominently emphasized issues in DT is its inherent and thorough *human-centred approach* (e.g. Brown, 2008; Porcini, 2009). Deriving from long practical experience and research, Meinel and Leifer (2015) argue that successful innovation through DT will always bring us back to the human-centric point of view: "This is the imperative to solve technical problems in ways that satisfy human needs and acknowledge the human element in all technologies and organizations." (Meinel and Leifer, 2015, p. 2) All depictions of DT are extremely consistent in emphasizing developing empathy towards the user, to have a deep understanding of their motivations, needs, and fears (e.g. Lockwood, 2009; Clark and Smith, 2008; Dunne and Martin, 2006). In order to achieve the deep and empathic understanding of the user, DT employs observational and ethnographic methods (e.g. Beckman and Barry, 2007; Carr, Halliday, King, Liedtka, Lockwood, 2010), as well as collaborative design with the user (e.g. Boland and Collopy, 2004; Brown 2008).

The Design Thinking process can be viewed as an exploration of a problem space and solution space, i.e. within the scope of the challenge, identifying and evaluating alternative problems to be solved and different solutions to address the chosen problem. In terms of cognitive processes, it is a combination of divergent and convergent thinking, where a set of choices is first created, and only then are choices made between the alternative options (Brown, 2009, 67). Ratcliffe (2009) describes DT as a six phase, iterative process involving back-and-forth movements between the different phases (Figure 1).

The process begins with *understand*; forming a general understanding of the situation and challenge at hand, and formulating an initial problem statement. During this phase, a product development team speaks with experts, conducts background research on the topic, and develops their understanding of the challenge to a level that allows them to identify ways to address the design challenge. While developing solutions to design problems is a well-recognized skill of designers, the ability to think up new ways of looking at the problem in the first place is key as well (Dew, 2007). This ability is referred as reflective reframing of the problem or situation. Design thinking encourages questioning the way a problem is represented (Boland and Collopu, 2004), looking beyond the immediate boundaries of the problem to ensure the right question is being addressed, and identifying, framing, and reframing the problem to be solved are seen as equally important as solving the problem or finding an appropriate solution (Beckman and Barry, 2007; Drews, 2009).

One of the outcomes of the understand-phase is the identification of key stakeholders and potential users. This gives the team an entry-point to the second phase, *observe,* where the objective is to learn how people behave and interact in the context of the challenge. This phase is also called *needfinding,* as the aim is to develop a deep understanding about the needs and problems of the user. At this phase the ethnographic research methods come to play, and where empathy for the user is developed. In addition to observation, the methods deployed here, include for example interviews, shadowing, “living the life of the user” i.e. immersing to the experience the user goes through.

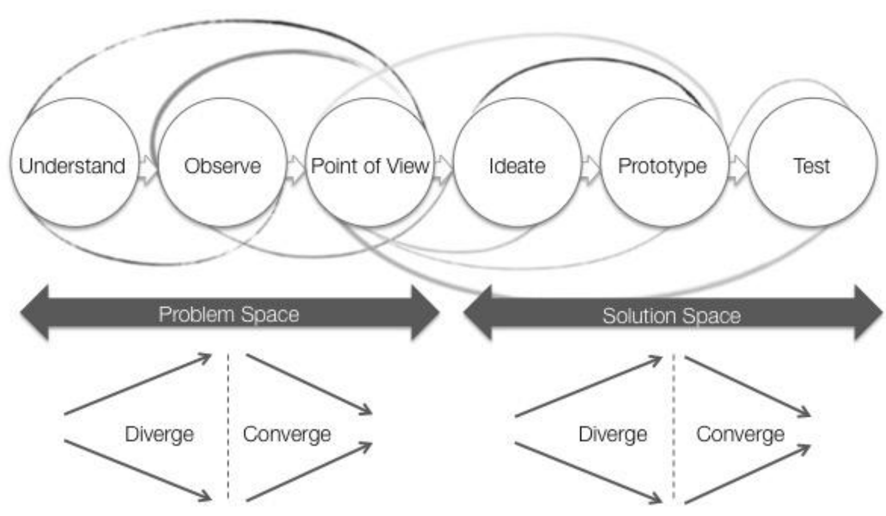

Figure 1. *Steps in a Design Thinking process (adapted from Ratcliffe, 2009)*

When defining *a point of view*, the team analyses and draws conclusions from the findings of the previous phases: are there patterns, surprises, meaningful details that could give direction to the following phases. This phase is essentially about reflecting on the information created and collected so far, and interpreting that into a new, better focused and defined problem statement. Here, an often used model for the reformulation of the problem starts with the question "How might we ." which is followed by the description of the user, his/her need and a specific insight that gives clues for a possible solution. This point of view statement becomes the starting point for idea development (e.g. Ratcliffe, 2009).

When *developing ideas*, quantity is encouraged (e.g. Brown, 2009, p. 67, 77-79). The challenge is to cover as much of the potential solution space as possible, and to do so the team must suspend judgement. Ideation it itself is an iterative divergence and convergence, where idea generation is followed by their analysis and selection, and then a new ideation round is done to either increase variety amongst the existing idea, or to produce detail to the already existing ones. Selected idea(s) are then prototyped and tested.

Early, rough, and quick prototyping is a central part of the iterative and highly tangible approach favoured by designers - and a cornerstone of DT. Early – "from day one" – and continuous prototyping is considered necessary and beneficial throughout the entire process (e.g. Brown, 2008; Fraser, 2007). *Quick prototyping* refers to creating many inexpensive and rough conceptual artefacts, to promote reflection and the generation of new ideas (Fai, 2011). Prototypes are, in fact, primarily seen as a tool for stimulating thinking and exploring ideas, not as representations of the products (Boland and Collopy, 2004). They are created to facilitate thinking and knowledge creation, to make concepts concrete, and to help the exploration of numerous possible solutions (e.g. Fraser, 2007, 2009; Lockwood, 2009). They are low-cost representations of the idea: sketches, cardboard models, or rough digital mock-ups, that are created with the purpose of receiving early feedback from the users with minimum investment of resources. The less is invested, the easier it is to modify the direction of the project if the received feedback so requires.

Testing the prototype with users shows what works, what doesn't. Reflection on the information gained from testing gives direction for the next iteration, i.e. how the idea and the prototype need to be modified. The process of challenging the original problem is not limited to the beginning of the process, but is ongoing, incorporating the findings already gained to re-phrase the problem (Drews, 2009)

Analytical Design

In the classical product development process, we can define a project as a connected sequence of unique and complex activities, with a single goal or purpose that should be completed in a specific time and with a given budget, according to a specification (Ulrich-Eppinger, 2008). This type of process assumes a certain level of knowledge upfront and during the project development. It consists generally on a sequence of steps or activities, usually six or more, that the designer or company employs to conceive, design and manufacture a product (Figure 2). The concept development is the key activity that demands more coordination among the other functions. It includes the following activities depicted in the lower part of Figure 1. In practice this activities may overlap in time and iteration is often necessary.

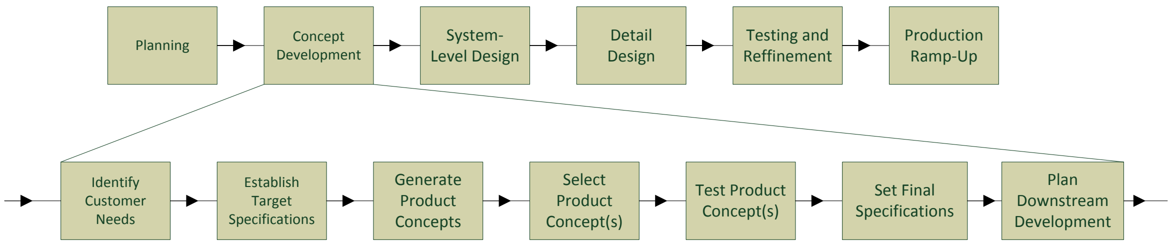

Figure 2. *Phases of product design and detailed phases of Concept Development. Adapted from* Ulrich-Eppinger (2008)

It is probably not needed to provide a detailed explanation of the classical approach. Most engineering schools teach and use a given variation of this approach. If we had to cite three references, we would choose the already cited (Ulrich-Eppinger, 2008) as a modern view of classical design, (Elder, 2008) as a reference book and the Lips model (Svensson, 2011) as an educational project model developed in Linköping University as a result of its participation on the CDIO initiative.

Model Comparison

If we look at the block diagram that describes the phases of design according to the Design Thinking approach (figure 1) and compare them with those depicted in the diagram of the "Concept Development" phase (figure 2, lower part), it may look like both are describing the same process. Apparently both start with understanding (needfinding) the customer needs, both stablish target specifications (Point of View), both develop several product concepts (ideate) ant test them through prototypes, to finish with a single product concept defined through final specifications. Where is then the difference? When engineers start dealing with "Identify Customer Needs", they usually know that the product is a given device, e.g. a wheelchair, and the needs are defined around the use of this device and the alternative analysis is performed on variations of this device or their parts. The same alternative analysis in the DT approach is not even in a preliminary phase of the solution but in the different needs identification in a given, broad environment e.g. elder mobility.

The design process assumes a certain level of information upfront and during the project development. According to Loch, "*Main reason for project failure is that organizations do not recognize the fundamental difference between project novelty and project risk Novel projects pose unforeseeable uncertainty*." (Loch et al. 2006, pp. 2-3). In today's projects, complexity is increasing and the risk of product failure in the market is extremely high. Companies have to deal with a high level of uncertainty in innovation projects. In many cases there is not enough information and it is not possible to precisely describe and define neither the current state nor the expected outcome. Moreover, in innovation projects there could be (and usually is) that one problem has many possible and different outcomes.

Loch et al. (2006, p. 74)) identify three fundamental project risk management approaches in face of uncertainty: the planning approach, iterate and learn approach, and selectionist approach.

The planning approach (with contingency and residual risk) could be considered the most classical approach, and is deployed when entering a known solution space. In this approach, the important problem solving occurs at the beginning of the project and then the emphasis shifts to executing the plan. There is a relatively high level of certainty and plenty of information at the outset. The outcome depends on the input at the beginning of the project, which proceeds with a pre-made plan with strong organizational pressure to support it.

The iterate and learn approach is well suited for projects in unknown solution space. It starts by planning and moving toward one outcome, which is the best that can be identified, with the information available upfront. The project team must remain prepared to repeatedly and fundamentally change both the outcome and the course of action as the project proceeds. This is due to the high level of uncertainty and lack of information available when starting the project. As new information becomes available, better-informed decisions can be made. This may force to iteratively modify the outcome.

The selectionist approach is characterized by pursuing multiple paths; independently of one another, and picking the best one ex post characterize this approach. As the "iterate and learn approach", this approach is well suited for unknown solution space, where the level of uncertainty is high at the beginning. As the project moves forward, more information is generated allowing deciding which paths to follow and which ones to discard.

In a simplified analysis, the first and more systematic approach is the one usually employed in classical engineering design, and this allows using modeling and analytical tools to optimize both the design process and the design results. Systems of Systems approach (Keatinget al., 2011) or Complex Systems Architecture (Crawley et al., 2015) provide focus and analytical tools to deal with very complex systems in a known environment. However, in uncertain environments, such as for example the creation of novel products, services or processes, the project outcome or the means to reach it are unknown at the outset of the project. Here, the iterate and learn, and the selectionist approach provide a more suitable support for the development process. Design Thinking is essentially aimed at creating information and knowledge. Hence, it bears strong resemblance to the iterate and learn approach, that relies on creative problem solving and reframing as the project proceeds.

The design-build project courses in the ICT degree curricula of Telecom-BCN at UPC mainly follow the classical approach. Although near half of the projects are specified by external companies or institutions, very few (one or two per year) involve a real contact with final users (e.g. medical doctors, nurses or patients), while the usual contact with companies is through R+D staff, usually engineers. The Telecom school has however had the opportunity of participating in a singular experience the last two years, a Challenge Based Innovation course promoted by CERN in which students from different disciplines and countries are challenged to design solutions to social needs following the DT approach. It is described in the following point.

THE CBI EXPERIENCE: MIXING DESIGN, MANAGEMENT AND ENGINEERING STUDENTS IN CHALLENGE-BASED PROJECTS

The European Organization for Nuclear Research, CERN, has been carrying out groundbreaking fundamental research in particle physics for over 60 years, and has made numerous important discoveries in the field - latest being the Higgs boson in 2012. It's current research gathers over 12 000 scientists from around the World in a collaborative effort in scientific experiments, developing new hardware and software solutions for their instruments. Over time, some of the research discoveries and instruments have found their way to wider audiences and have had significant impact on our everyday life, as in case of the World Wide Web.

IdeaSquare

The process of discovering the relevant societal applications is nevertheless slow, sometimes taking even decades, and many good applications so far have been adopted through serendipitous coincidences. In order to shorten the time gap between the research and its application in a structured way, a new innovation experiment called IdeaSquare was set up by CERN in 2013 in collaboration with Aalto Design Factory, a multidisciplinary teaching and development unit inside Aalto University in Finland. The main purpose of IdeaSquare is to explore new ways to demonstrate the value of applying fundamental research concepts to societal challenges. For this effect, IdeaSquare is hosting long-term research projects on detector R&D, promoting different innovation-related events and hackathons and facilitating multidisciplinary student projects like the Challenge Based Innovation (CBI).

Challenge Based Innovation

CBI is an experimental, human-centric product development project structure hosted by IdeaSquare. In CBI, multidisciplinary student teams start from a societal need and obtain relevant end-user needs to be addressed. Together with CERN mentors, teams draw inspiration from relevant novel technologies and create tangible prototypes to e.g. help autistic children in their learning process or developing methods for longer food storage. The CBI structure is a prototype itself and its purpose for IdeaSquare is to find out whether these kinds of design methodologies can bring value in the highly technological context of CERN. In the mission of CERN (Figure 3), CBI is focused on Collaboration and Education, with slighter focus on Technology and Research. To ensure a strong connection to CERN, all the teams have an assigned CERN mentor or research group they collaborate with throughout the project. They also have a coach in their home university with whom they have weekly sessions and who facilitate the team's advancement (Table 1)

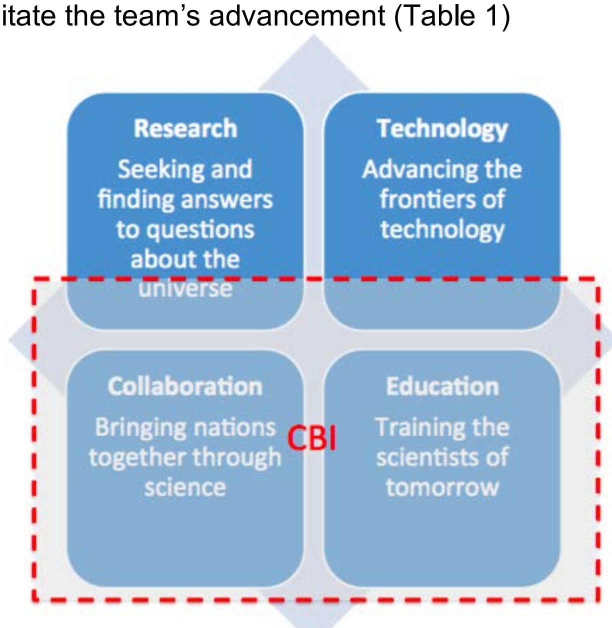

Figure 3. *CBI's focus within the mission of CERN (source: CERN website)*

Aligned with the DT approach, the basic structure of CBI is divided into three parts: Discover, Design and Deliver. The three phases of CBI are similar to e.g. the Design Council's double diamond model, composed of four phases, and the ME310 model, which has three main phases (Carleton & Leifer, 2009; Design Council, 2005).

In the Discovery phase, the student team does a deep dive into the societal need which they are given, and seeks to understand the fundamental constellation of the project. Need-finding, benchmarking and basic research about the project context are done with the goal of understanding the user and the field of operation. The phase ends with the team defining a specific need or a problem they aim to tackle. In the Design phase, multiple solutions for the discovered need are quickly prototyped and user feedback is gathered. Through learning from the prototypes, a final concept is chosen. In the Delivery phase, this concept is made higher in its resolution, and technical, design and user interface parts of the solution are implemented and integrated in a tangible prototype. The projects are finally presented in a gala event to the CERN and university audiences.

Table 1. Learning objectives and practical arrangements of CBI course

Learning objectives for students	**Practical arrangements**
• Develop highly futuristic, technologically feasible ideas that have the potential to challenge the status quo in socially and globally relevant human challenges. • Develop skills applying design thinking tools and methods and product design in a practical, real world project. • Develop skills in moving ideas into testable, tangible prototypes quickly. • Develop skills in interdisciplinary teamwork and communication.	• Each team will have 7-9 students coming together from two or more different universities. The team will be a multidisciplinary combination of students who have their background in engineering (mechanical, electrical, ICT), business and design. • The project topics will be confirmed and assigned during the kick-off week. Each team will be paired with a dedicated CERN mentor. • Project budget will be allocated for the teams for their exploratory prototypes during the process and for building the final, high-resolution prototype.

The topics for the course would be optimally formulated together with a societal problem owner and an expert institution e.g. an NGO working on the field. So far, some of the topics have been inspired from the CERN side, some from the collaborating universities' side and also from companies working on relevant areas. The topics are open rather than tightly framed, and the outcome is aimed to be educational for the participants beyond the pure project outcome.

The final deliverables for the CBI course were designed to give each project clear goals and to ensure that the most relevant learning objectives (Table 1) would be covered. Usually in a project, user testing is one of the things that is not often done to the full extent. To emphasize this point together with the impact calculation, they were separately mentioned.

1. Proof-of-concept prototype
2. User test results
3. Impact demonstration
4. CERN connection
5. Final presentation with relevant materials
6. Final documentation describing the project and process
7. Final video

Examples of projects developed into the CBI course

The last two academic years, design, management and ICT engineering students from Istituto Europeo di Design (IED), ESADE Business School and UPC-Telecom BCN were mixed together in multidisciplinary teams and also together with students from another international universities and similar disciplines. Being the three mentioned institutions located in Barcelona, the local student teams (5-6 students each) could work together at least one full day per week when they weren't at CERN, and could contact via Skype with the international partners. Examples of the challenge statements and the resulting solutions are described in Table 2. Other four challenges not described in this table were also completed.

Table 2. Examples of the challenges in the two last editions of CBI course

Challenge statement	Solution developed and prototyped
How can we design a wearable system that allows the users to access information about their effect on others around them by deepening the understanding of these interactions?	A wearable system that helps people with Asperger's syndrome to learn about how close come to another person and how fast and loud has talked to him/her.
How can we design a viable system that allows people to restore or enhance their ability to move?	A flexible skirt with an "airbag" and a set of sensors and algorithms that triggers it when a fall is detected to prevent hip fracture in elder women.
How might we improve public health by providing safe access to water?	A low-cost sensor set-up that detects if a given well in Africa is working and a network to inform users about the well state and to manage the repairing if needed.
How might we home deliver food in a new way that maintains the food cold, at a selected temperature, ensuring its safety?	A food transportation box that combines a special isolation material, partial vacuum and RFID active tags to reduce the cooling needs and to give information on the order state to both the customer and the provider.

A description and a report of the projects performed in the academic year 2014-2015 are available at http://2014.cbi-course.com . The description of the projects performed the current academic year will be soon available in the same site.

DISCUSSION AND CONCLUSIONS

The overall result has been outstanding in both editions. Feedback from students in general and from engineering students in particular has been more than positive. Most of them have qualified CBI course as a key step in their curriculum. Several aspects which are not usually found in the regular courses can be found together in this one: Multidisciplinary and international composition of teams, which not only enriches the points of view taken into account when analyzing the challenges but also forces the students to negotiate in a wider environment than its usual class group; contact with CERN scientists as consultors and coaches and with CERN technologies, which raises the horizon of possible solutions to levels unforeseen by the students; singular workspaces, mainly at IdeaSquare, where the students work together and intensively during several periods in an environment that boosts the creativity; challenge-based projects with very open initial statements, which drive to the use of a methodology like Design Thinking, which takes the students out of his comfort zone and forces them to interact with end-users and stakeholders in several phases of the projects.

Although all students from the different disciplines are playing out of their field with the interdisciplinarity and the user-driven approach, the engineering students are probably the ones that experience the biggest perturbation respect to their previous training. One of the biggest tasks for coaches is to keep them calmed when they tend to apply technological solutions in the low-resolution prototyping phases during needfinding and ideation (two thirds of the project duration), where they are still not needed. They need a strong justification to participate in these phases exactly like the design or management students. Including engineers in the teams has the added value, set apart the enrichment of viewpoints, of allowing the implementation of true functional final prototypes, which could provide a realistic proof of concept to users, stakeholders or potential investors. A minor drawback of the involvement of engineering students is that they (and even the engineering teachers and coaches) use to reveal the technology limitations in the ideation phase, where disruptive solutions that go beyond the currently possible solutions could appear.

If compared with the capstone projects performed by the regular students at Telecom-BCN (Bragos et al., 2012) the results would be the following:

- The human resources allocated to the projects is quite similar. Although the local teams in CBI courses are smaller (5-6 students vs 8-12 students), they devote more time to the project thanks to the intensive weeks at IdeaSquare.
- While the CBI course students devote four-five weeks to needfinding, four more weeks to ideation (including low resolution prototyping and testing) and only four weeks to final solution prototyping, the usual structure of capstone projects at Telecom BCN is two-three weeks to fix specifications from initial requirements, six weeks to subsystems design and implementation and five weeks to system integration and refinement.
- As a consequence, the technical deepness and complexity of solutions is higher in capstone projects than in CBI projects, but the degree of awareness of what the product is and what does the user expect from it is clearly lower. Even some students in the team can be only devoted to technical tasks and miss the user/market orientation of the product and the business aspects. There are some exceptions in capstone projects,

when interlocutors are not engineers or technicians but end users (only 1-2 projects out of 6-9 per semester).

Multidisciplinarity in Telecom-BCN capstone projects is understood as the mixture of communications, electronics and networks or audiovisual systems engineering students, which is wider than having only students from a single discipline but is still limited to the ICT engineering field. In opposition, in CBI course, engineering students should learn to discuss with people that has a very different point of view, which is a relevant experience. CBI course has also been a great learning experience for the engineering teaching team. The user-driven approach is being introduced with a limited extent in the regular project courses by the faculty that has participated in CBI. Also coaching the engineering students that have been taken out of their comfort zone has been a great experience that has modified our way of thinking in engineering project education.

Albeit perhaps unintuitive, multidisciplinary learning experiences also support the development of the students' professional profile, and deepen the professional expertise in a respective field. In a learning context such as CBI, the successful development of the project depends on the specialized input delivered by each student, from his field of expertise.
Open-ended and problem-based projects allow the students to learn how to manage projects with uncertainty: how to proactively create information, reflect on it as a group (collaborative sensemaking) and adapt the direction of the project respectively. The experience develops the entrepreneurial skills and abilities of the students.

The benefits in the learning outcomes of the participants in CBI courses are cumbersome and, at least from the engineering students' point of view, cannot be foreseen before participating in the course. Design Thinking is a methodology that can only be learnt by doing. An immersion in that methodology like the one described in this work cannot be provided to all students, and even a large amount of engineering students would prefer projects with more technical content, but a basic knowledge of the basis of this methods would be very positive for everyone, and the possibility for the students more inclined towards innovation and entrepreneurship to participate in a learning experience like the one described is highly desirable.

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BIOGRAPHICAL INFORMATION

Lotta Hassi, M.Sc. (econ.), is a lecturer at Operations, Innovation and Data Sciences department of ESADE Business School. Her doctoral research focuses on management of explorative innovation projects of high uncertainty. She leads annually numerous multidisciplinary innovation projects at the intersection of educational organizations, research centers and the private sector.

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Luciana Leveratto is Master Academic Dean at IED Barcelona. With more than 20 years of experience in design education, she is dedicated to the content creation for new educational programs, new methodologies, coordination and development of multidisciplinary projects, and supervision of quality in educative programs.

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Guido Charosky is an Industrial Designer (UBA), has advanced research studies (DEA) from UPC and a Postgraduate in Business Management (EOI). He is co-founder of Drop-Design for Innovation, a consultancy firm focused on user experience innovation through design thinking for creating unique products & services. Before founding Drop, Guido has worked at HP as User Experience Design Lead and in strategic consulting leading innovation projects for big companies in different sectors (Technology equipment, FMCG, consumer electronics,) . He is also Coordinator of the Masters in Innovation Strategies & Entrepreneurship and professor at Istituto Europeo di Design (IED).

Tuuli Maria Utriainen is working at CERN as a part of the IdeaSquare initiative, experimenting with new forms of collaboration. Her work is focused on connecting universities and NGOs around the globe to solve human centred challenges with the help of CERN's technological knowledge. Tuuli started her academic venture at Information Networks program at Aalto University and she also studied Communications at Helsinki University. 2008 she joint Aalto Design Factory, a passion based platform for product development, where she ran product development projects in collaboration with many universities. All in all she's coached over 30 multidisciplinary product development teams in Europe, US, Asia and Australia.

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Annex B – Articles

Re: Permission to include article in PhD thesis

ijee <ijee.editor@gmail.com> jueves, 25 de marzo de 2021, 12:44

Para Guido Charosky

15_ijee4042.pdf
1,1 MB

Descargar todo Vista previa de todo

Respondió a este mensaje el 25/3/21 12:59. Mostrar respuesta

De: ijee <ijee.editor@gmail.com>
Fecha: miércoles, 17 de marzo de 2021, 12:12
Para: Guido Charosky <g.charosky@drop-innovation.com>
CC: John Turner <ijee.office@gmail.com>
Asunto: Re: Permission to include article in PhD thesis

Dear Guido,

Please feel free to include the article you mentioned (PDF format as published) in the repository of your university.

My best wishes,

Ahmad Ibrahim

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Investigating Students' Self-Perception of Innovation Competences in Challenge-Based and Product Development Courses*

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This study analyzes self-perception in innovation competences development in engineering students with the objective of understanding how to better design educational strategies to improve innovation skills in future engineering graduates. The INCODE (Innovation Competences Development)-Rubric 5 survey is used to compare two groups of engineering students from Telecom Engineering school from UPC (Technical University of Catalonia) going through two types of project-based courses: CBI (Challenge Based Innovation) course versus PDP (Product Development Project) course. CBI is an innovative learning experience carried out by three institutions: Telecom Engineering School of UPC, ESADE Business School and IED Istituto Europeo di Design in collaboration with CERN, where mixed teams of students from the three institutions face open innovation challenges through Design Thinking, with the objective of designing solutions to complex societal problems, considering the use of CERN technologies if suitable. PDP is the "standard" capstone course taken by Telecom engineering students following a classical project-management approach. Results show that both courses give a good self-perception of the learning outcomes in the innovation-related skills, according to what is observed in the INCODE surveys' results when comparing CBI and PDP. The differences found between CBI and PDP are small and only moderately deviated towards CBI in the individual competences dimension.

Keywords: innovation competences; challenge-based education; project-based learning; self-assessment

1. Introduction

Engineering education over the last 50 or 60 years has been mainly based on "engineering science", where engineering is taught only after a solid basis in science and mathematics [1]. This led to engineering graduates to be perceived by industry as "too theoretical", not being able to easily adapt to work due to this change from theoretical to practical [1].

This gap between academia and industry has been tackled through the creation of capstone design courses, allowing final year students to use their theoretical knowledge on a system level, working in "real" projects [1].

Institutions like ABET – Accreditation Board for Engineering and Technology [2], NAE-National Academy of Engineering [3] in the United States and ENAEE – European Network for Accreditation of Engineering Education [4] in Europe, highlight these demands for future engineers' competences. The expectations and needs for future graduates go way beyond the purely technical skills and demand innovation competences. As an example, Radcliffe [5] describes the skills and knowledge that engineering innovators should possess, arguing that innovation is an integrative meta-attribute overarching most of the other engineering graduate attributes.

Innovation competences are often associated with those for entrepreneurship and even though they are related, it is good to differentiate them.

Entrepreneurship is normally associated with starting a business whereas innovation is also about wider "economic and social wellbeing" [6]. Simply put, innovators are people who generate new ideas and entrepreneurs are those who take ideas, whether are new or not, to market.

Innovation competences are "the learning outcomes which refer to knowledge, skills and attitudes needed for the innovation activities to be successful" [7]. Some of the most relevant innovation competences, as described in different papers are creativity, creative problem solving, problem identification, independent thinking, openness to new ideas, research focus, teamwork, forward-looking approach, among others [7–9].

Nevertheless, there is much debate on what exactly are the innovation capabilities needed, and specially on the instrument to be used for identifying and measuring the acquisition of these innovation skills [10].

Innovation has an inherent social dimension that

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Fig. 1. Innovation competence model. Adapted from Penttilä and Kairisto-Mertanen [13].

makes it transcend mere invention or enhancement of a product or process [11]. Innovation competences can be defined as a cluster of diverse, sometimes overlapping skills and capacities that altogether form empowers an individual to successfully innovate.

Finally, as argued by Belkhir, Fleisig & Potter [12], when speaking about teaching innovation to engineers, the approach should be focused on innovation that "foregrounds societal impact as opposite to technical progress".

1.1 The INCODE Project

The Innovation Competencies Development (INCODE) project is a European research project developed by four Universities: Turku University of Applied Sciences from Finland, Hamburg University of Applied Sciences from Germany, Karel de Grote University College Antwerp from Belgium and the Universitat Politècnica de Valencia from Spain.

The INCODE innovation construct is based on three dimensions at a competence level: individual, interpersonal and networking as shown in Fig. 1, following the model proposed by Penttilä and Kairisto-Mertanen [13] for measuring innovation competences in higher education students.

As defined by Watts, García-Carbonell & Andreu-Andrés [11] "the individual capacity integrates the behaviors or skills that allow a person to innovate in the personal execution of tasks. The interpersonal capacity enhances the individual ability to innovate through the interaction with a group and represents the behaviors or skills that make others move towards the objective. The networking capacity represents the behaviors or skills that enable a group to find appropriate solutions in the process of completing tasks in a broader environment than usual."

These three dimensions are better described and defined by Marin-Garcia, Ramirez-Bayarri & Andreu-Andrés [14], structuring the three dimensions in specific innovation competences as shown in Fig. 2.

- Individual: creativity and critical thinking.
- Interpersonal: teamwork and leadership.
- Network: networking and impact.

The Innovation Competencies (INCODE) Barometer aims to contribute to developing and assessing innovation competences in higher education contexts [11].

The INCODE Barometer is a scoring rubric that covers the three dimensions of skills and capacities: individual, interpersonal and networking. The skills corresponding to each category are listed in tables 2, 3 and 4, in the Results section.

The Barometer can be used in several ways: self-assessment, peer assessment and also by teachers to assess students' learnings outcomes.

Within the Barometer there are two groups of rubrics to assess innovation competence performance: Rubrics 1, 2 & 3 to for teacher/peer assessment and rubrics 4, 5 & 6 for self-assessment. They differ in the choice of scale: 1–10, 1–5 and 1–3 and a category for Not observed or Not demonstrated.

Watts, Marin-Garcia, García Carbonell & Aznar-Mas [15] argue that "no formal system has been regulated to acquire and assess the skills and

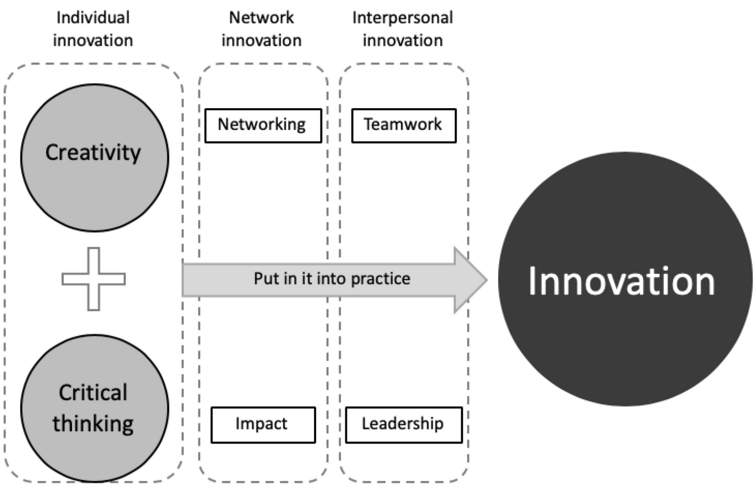

Fig. 2. Innovation model. Adapted from Marin-Garcia, Ramirez-Bayarri & Andreu-Andrés [14].

capacities involved" regarding the certification of the components of innovation competence. Thus, INCODE is a good step forward on systematizing the assessment of innovation competences, aligned with the methods proposed by Prus & Johnson [16] to assess "professional skills" in students, with Atman, Adams, Cardella, Turns, Mosborg & Saleem [17] that mentioned metrics on the process of innovation and individual's creative personality and Bandura's [18] proposed reflective essays and self-efficacy concept.

Having two type of project-based courses with UPC students in parallel for 5 years enabled the opportunity to analyze and compare students' results with the aim of identifying strategies to better develop innovation competences in engineering students.

In this study the Rubric 5 of the INCODE Barometer is used to compare the self-assessment of students participating in PDP and CBI courses related to innovation competences, drawing conclusions and discussions on how to better design educational strategies to improve innovation competences in future engineering graduates.

2. Presentation

2.1 PDP – Product Development Project

When designing the engineering degree curricula according to the EHEA directives, the Telecom Engineering School adopted the CDIO Standards [19] and, as part of the implementation of the CDIO model (CDIO Standard 5), included a project courses path which currently includes a design-build, project-based course in the second, third and fourth year of the bachelor. In the 4th year, mixed teams of students from the different minors of the Telecom Engineering degree (Electronics, Networks, Audiovisual Systems and Communication Systems) face a complex technical challenge defined by a company or external institution, designing and implementing the different parts of the project and finally integrating and testing the product, process or service, including a functional prototype and the definition of a business model. It is a Product Development Project (PDP) course that follows a "traditional" project management approach as described by Ulrich and Eppinger [20].

Students interlocutors during the project are UPC supervisors and technical staff (typically engineers) from the companies/institutions posing the challenges. The focus is mainly narrowed to technology and technical solutions. The specifications and requirements for these projects are normally well defined, and companies come already with a solution in mind of what they expect students to develop. Some examples of projects are image and video processing software for rehabilitation of facial paralysis due to facial nerve injury, human-machine interface techniques for car cockpit, development of sensors for 3D printers, distributed satellite system projects around a Cube-Sat platform or blockchain-based payment distribution system in the music industry.

2.2 CBI – Challenge Based Innovation

Challenge Based Innovation (CBI) is a program created by IdeaSquare at CERN, the European Organization for Nuclear Research, to host educational projects where students from different disciplines working in multidisciplinary teams (engineering, design and management) tackle innovation challenges through Design Thinking. The objective is to design solutions to complex societal problems, considering the use of CERN technologies if suitable [21]. CBI among other features, has a positive effect on the entrepreneurial intentions of the participating students as demonstrated by Palomäki [22].

Since 2015, students from UPC have the opportunity to enroll in CBI course (Challenge Based Innovation) alternatively to PDP (Product Development Project) course, which is mandatory for all Telecom Engineering students. It is an innovative educational experience carried out in collaboration by three higher education institutions: UPC (Telecom and Computer Science students), ESADE Business School and IED Barcelona (Istituto Europeo di Design). It is currently in its 6th edition. It is a challenge-based experience [23] with a user centric approach using Design Thinking [24].

In CBI course, multidisciplinary teams of students from UPC (engineering), ESADE (business) and IED (design) tackle complex societal challenges, defined in collaboration with NGOs, institutions and IdeaSquare team. The topics are broad allowing a great range of possible solutions and how to approach them is up to the students. The aim is more oriented to learning outcomes than to technical solutions. Since the past 2 editions, UN Sustainable Development Goals (SDG) are taken as a basis for defining the challenges. For developing their CBI projects, students immerse in the challenge and engage in interviews and observation with users and stakeholders in real context. They identify the needs and define the specific problem to be solved within their original broad challenge. They later ideate, prototype and test their solutions in real context with real users, and also develop the business model as well as the technical solution. Finally, they present their project at CERN, in a gala in front of scientists, companies and university audience including media coverage. During CBI, students have dedicated sessions and classes of user research, ideation, prototyping, business modeling and entrepreneurship (among others) with professors from the three schools (business, design and engineering). Some examples of CBI projects are: Starting with a challenge statement which was to improve the quality of life in refugees' shelters, the students identified (after visiting a refugees' camp and interviewing experts from the UN Refugee Agency) that there was an unattended need in the electrical power distribution, and designed and prototyped a low-cost smart grid for refugees' camps as solution. Another challenge was to improve the inclusion in society of adults with intellectual disability. The students learnt, from interviews with stakeholders, that there was an issue with their communication capabilities and that the computer-aided speech therapy was not adapted to the needs of these individuals, so they designed a solution with tailored stimuli. A third example had the very open challenge of improving human mobility. After considering several target groups, the students focused on elder people and specifically on elder ladies which, due to the high risk of hip bone breaking, were afraid of moving. As a solution, they designed and prototyped a flexible skirt with lateral airbags which were triggered when a fall-down was detected through sensors and AI algorithms. As it can be inferred from the examples, in the CBI course, the students are asked to choose a relevant need through field research and design and prototype a disruptive solution, also including user testing and feedback.

The framework for the current research is the comparison of the self-assessment on innovation competences of students from UPC taking the PDP course versus the ones taking CBI Course. Given the different approaches of both courses, PDP more technical and CBI more user-oriented, our initial hypothesis was that the CBI course would provide a higher self-perception on Innovation-related skills, as the teams in that case can generate more original and disruptive solutions.

3. Research Methodology

The research methodology aims to analyze, identify and compare the engineering students' innovation competences based on their self-perception, acquired in the CBI courses vs. the students' innovation competences acquired in PDP "standard" project-based courses using the Rubric 5 of the INCODE Barometer.

3.1 Participants and Sampling

The sample of the study is a purposive sampling [25], aiming to have a homogeneous sample, as described by Patton [26] with the purpose of comparing two particular subgroups of telecom engineering students: those who followed PDP course vs. those who followed CBI course in the period of 2015–2019.

In all cases, students took a project-based course working on real challenges either from companies, institutions and/or social challenges developing a solution and a working prototype as deliverables of the course.

As mentioned above, the results analyzed are the comparison of two groups of students of Telecom Engineering from UPC (Technical University of Catalunya).

Group 1 – PDP: students that took the capstone project (Product development project) course called Advanced Engineering Project, which follows a "traditional" project management approach [20].

Group 2 – CBI: students that took, instead of the PDP, the CBI (Challenge Based Innovation) course, which follows a challenge-based approach [23] using Design Thinking [24, 27].

The total population of interest can be established as for all Telecom students is mandatory to take one course or the other.

It is important to highlight that all students are by default required to take the PDP course since 2012, and since 2015 they have the opportunity to opt to take CBI course in exchange. This involves a potential risk for the study, given that to be accepted to participate in CBI course students must apply presenting their grades and a motivation letter. This means that those students taking CBI are among the top students and might be already prone or have a certain bias to better develop innovation competences compared to PDP students. Nevertheless, it is worth to mention that this can also be mitigated due to the fact that PDP course happens twice a year (in both Fall and Spring terms) and CBI only happens in the Fall term (once a year). Thus, students that take their 4th year project-based course in the Spring term can only take PDP and they cannot opt to take CBI.

3.2 Sample Size

As suggested by Cresswell [28] and Cohen, Manion & Morrison [25] the minimum rough estimate for educational research is approximately 15 participants per group in an experiment and 30 participants for a correlational study to develop a statistical procedure. Even though there are not fixed numbers for participants for a quantitative study, the above mentioned led us to state that the numbers are enough to extract relevant insights and conclusions, given that as both PDP and CBI respondents are more than 30 each.

The INCODE survey was sent to 959 students, who have taken PDP or CBI course during the period of 2015 to 2019. Obtaining an average response rate of 8.4%.

3.3 Data Collection

To collect the data, the INCODE Barometer was used, sending via email to the students, who had taken either CBI or PDP, a link to a Google Forms with the Rubric 5 of the Barometer [11], asking them to reflect their self-assessment on innovation competences acquired.

The total number of respondents was 81, being 49 from PDP and 32 from CBI. The number of responses per years was: 11 in 2015 (14%), 9 in 2016 (11%), 17 in 2017 (21%), 18 in 2018 (22%) and 26 in 2019 (32%).

From the total sample of respondents (81), there is a 73% (59) males and 27% (22) females, which is representative in the technical University of Catalunya, which has 25% of females of its total population [29].

4. Results

In a scale of 1 to 5, we got answers in the whole range, from 1 to 5. All answers' averages were in the high segment of the scale, in the range 3.59 to 4.56 for CBI and 3.45 to 4.57 for PDP. Fig. 3 shows the means of the answers for the 25 questions of the INCODE – Rubric 5 for both groups.

The results were analyzed using JASP version 0.11.1, an open-source statistical analysis tool developed by University of Amsterdam, The Netherlands. The independent samples t-test was used to estimate the effect size and test the one-sided alternative hypothesis that the mean of the answers of CBI group are bigger (or smaller) than the mean of the answers of PDP group for each question. The sign of the difference between means was used to determine the sense of the hypothesis tested. The percentage of the difference among means has been calculated respect to the CBI mean value for each case. To consider a hypothesis as validated (so discarding the null hypothesis), we have considered the usual threshold of $p < 0.05$, although we have mentioned in several cases differences with p-value between 0.05 and 0.1 as "moderately significative" or "non-negligible".

Comparing the aggregated answers of the three dimensions and the overall set of answers (Table 1), the total average score of CBI is 4.09 and for PDP is

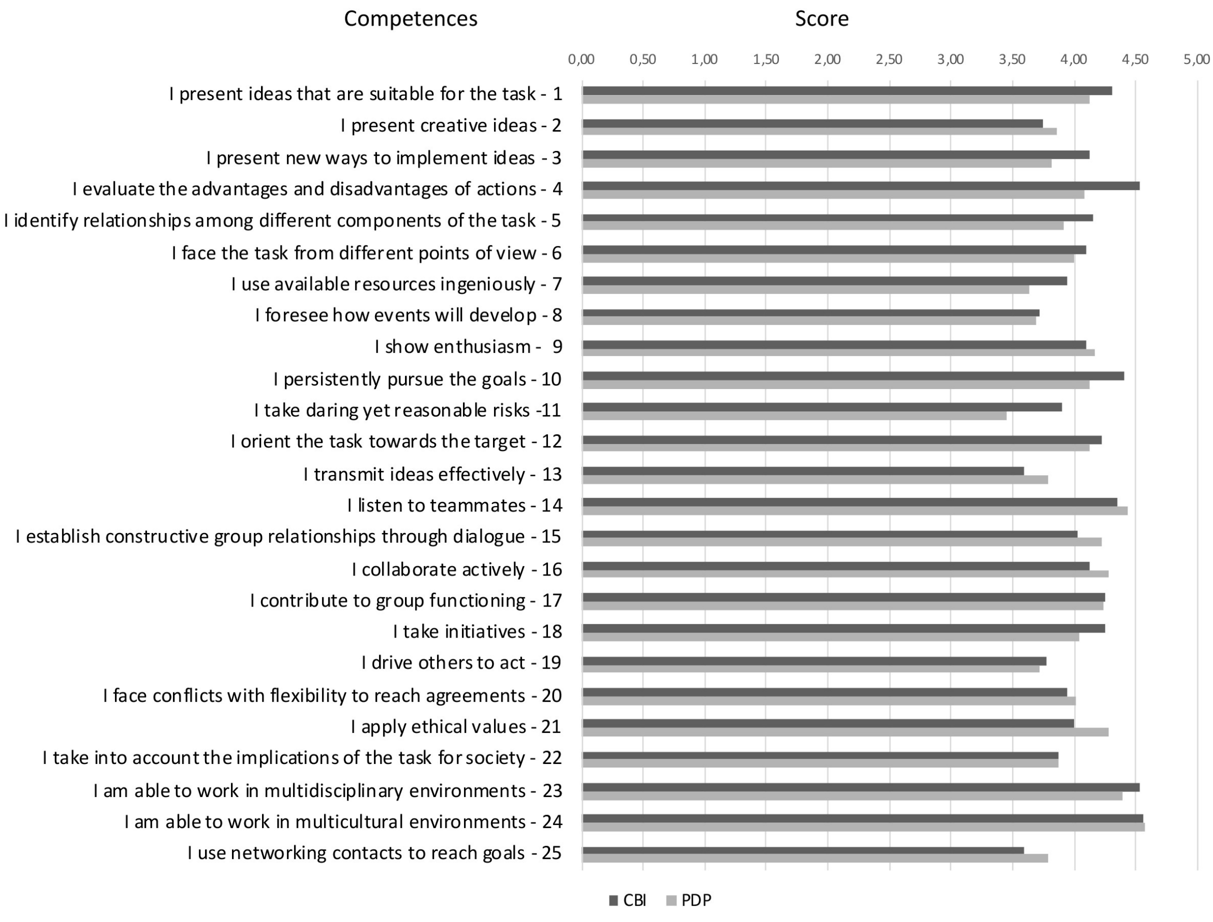

Fig. 3. INCODE Rubric 5 – Innovation competences self-perception results CBI vs. PDP courses.

Table 1. INCODE Rubric 5 – Dimensions Aggregated Results CBI vs. PDP

	CBI (n 32)			**PDP** (n49)							
Dimension	**n**	**mean**	**SE**	**n**	**mean**	**SE**	**Mean diff.**	**%**	**Hyp.**	**p**	**Validation**
Individual	384	4.10	0.04	588	3.92	0.04	0.19	4.6%	>	0.0002	✓
Interpersonal	256	4.04	0.05	392	4.09	0.04	–0.06	–1.5%	<	0.1990	✗
Networking	160	4.11	0.08	245	4.18	0.06	–0.07	–1.7%	<	0.2280	✗
Aggregated	800	4.09	0.03	1225	4.03	0.03	0.06	1.5%	>	0.0620	~

Mean differences (absolute and relative %) and one-sided null-hypothesis p-values and rejection validation using the following significance level thresholds and symbols: Null-hypothesis rejected ✓: $p \leq 0.05$; marginally rejected ~: $0.05 < p < 0.2$; non-rejected ✗: $p > 0.2$.

Table 2. INCODE Rubric 5 Individual Competences Results, CBI vs. PDP

		CBI (n = 32)		**PDP** (n = 49)						
#	**Individual competences**	**mean**	**SE**	**mean**	**SE**	**Mean diff.**	**%**	**Hyp.**	**p**	**Validation**
1	I present ideas that are suitable for the task	4.31	0.11	4.12	0.10	0.19	4.4%	>	0.1040	~
2	I present creative ideas	3.75	0.15	3.86	0.12	–0.11	–2.9%	<	0.2890	✗
3	I present new ways to implement ideas	4.13	0.13	3.82	0.12	0.31	7.5%	>	0.0500	✓
4	I evaluate the advantages and disadvantages of actions	4.53	0.10	4.08	0.11	0.45	9.9%	>	0.0030	✓
5	I identify relationships among different components of the task	4.16	0.14	3.92	0.12	0.24	5.7%	>	0.1040	~
6	I face the task from different points of view	4.09	0.14	4.00	0.12	0.09	2.3%	>	0.3080	✗
7	I use available resources ingeniously	3.94	0.16	3.63	0.15	0.31	7.7%	>	0.0870	~
8	I foresee how events will develop	3.72	0.12	3.69	0.11	0.02	0.7%	>	0.4410	✗
9	I show enthusiasm	4.09	0.15	4.16	0.11	–0.07	–1.7%	<	0.3500	✗
10	I persistently pursue the goals	4.41	0.11	4.12	0.10	0.28	6.4%	>	0.0360	✓
11	I take daring yet reasonable risks	3.91	0.12	3.45	0.13	0.46	11.7%	>	0.0100	✓
12	I orient the task towards the target	4.22	0.12	4.12	0.11	0.10	2.3%	>	0.2780	✗

Mean differences (absolute and relative %) and one-sided null-hypothesis p-values and rejection validation using the following significance level thresholds and symbols: Null-hypothesis rejected ✓: $p \leq 0.05$; marginally rejected ~: $0.05 < p < 0.2$; non-rejected ✗: $p > 0.2$.

4.03. The difference between the two means is only 0.06 representing only a 1.5% in favor of CBI ($p = 0.06$) as can be observed in Table 1.

Regarding the aggregated answers by dimensions, there are also similar results but with a bigger difference for the Individual dimension. It performs significatively better in CBI (mean difference of 0.19, 4.6%, $p = 0.0002$). The Interpersonal and Networking dimensions perform slightly better in PDP, but the difference is not significative (p in the range of 0.2 in both cases).

When looking at the specific competences, the ones with the bigger differences (5% or more) belong mostly to the Individual competences dimension. Table 2 displays the means, standard errors, differences among means and p-values of the 12 competences of the individual dimension.

The competences with mean differences bigger than 5% and statistically significative ($p \leq 0.05$) are number 3, 4, 10 and 11. They will be commented in the discussion section. Competences 1, 5 and 7 have non-negligible differences, near 5% but the difference is marginally significative ($0.1 \leq p \leq 0.05$) because of the higher dispersion in the answers. All the other competences give small and non-significative differences, including the only one which gives a slightly better result for PDP than for CBI in this individual dimension, competence 9.

In the Interpersonal competences dimension (Table 3), they display small and non-significative differences ($p > 0.1$) with both positive and negative signs. Only one (competence 18, I take initiatives) gives a p value in the border of 0.1 with a positive difference of 4.9% towards CBI.

Finally, in the Networking Competences (Table 4) the differences among means are also small and with high p-values, with the only exception of competence 21 (I apply ethical values) which gives a difference towards PDP of 7.1% with $p = 0.083$, the only negative difference moderately significative.

Table 5 displays the top 5 highest ranked competences in both courses. There are 3 which are common for both courses, and it is remarkable that in both cases the top 1 is the same one.

Table 3. INCODE Rubric 5 Interpersonal Competences Results, CBI vs. PDP

		CBI (n = 32)		**PDP** (n = 49)						
#	**Interpersonal competences**	**mean**	**SE**	**mean**	**SE**	**Mean diff.**	**%**	**Hyp.**	**p**	**Validation**
13	I transmit ideas effectively	3.59	0.14	3.80	0.12	–0.20	–5.6%	<	0.1370	✗
14	I listen to teammates	4.34	0.13	4.43	0.12	–0.09	–2.0%	<	0.3250	✗
15	I establish constructive group relationships through dialogue	4.03	0.12	4.22	0.12	–0.19	–4.8%	<	0.1380	✗
16	I collaborate actively	4.13	0.15	4.29	0.11	–0.16	–3.9%	<	0.1960	✗
17	I contribute to group functioning	4.25	0.12	4.25	0.10	0.00	0.1%	>	0.4870	✗
18	I take initiatives	4.25	0.12	4.04	0.11	0.21	4.9%	>	0.1050	~
19	I drive others to act	3.78	0.13	3.71	0.13	0.07	1.8%	>	0.3650	✗
20	I face conflicts with flexibility to reach agreements	3.94	0.15	4.02	0.10	–0.08	–2.1%	<	0.3190	✗

Mean differences (absolute and %) and one-sided null-hypothesis p-values and rejection validation using the following significance level thresholds and symbols: Null-hypothesis rejected ✓: $p \leq 0.05$; marginally rejected ~: $0.05 < p < 0.2$; non-rejected ✗: $p > 0.2$.

Table 4. Networking Competences Results, CBI vs. PDP

		CBI (n = 32)		**PDP** (n = 49)						
#	**Networking competences**	**mean**	**SE**	**mean**	**SE**	**Mean diff.**	**%**	**Hyp.**	**p**	**Validation**
21	I apply ethical values	4.00	0.17	4.29	0.12	–0.29	–7.1%	<	0.0830	~
22	I take into account the implications of the task for society	3.88	0.19	3.88	0.15	0.00	–0.1%	<	0.4960	✗
23	I am able to work in multidisciplinary environments	4.53	0.09	4.39	0.10	0.14	3.2%	>	0.1610	✗
24	I am able to work in multicultural environments	4.56	0.09	4.57	0.09	–0.01	–0.2%	<	0.4730	✗
25	I use networking contacts to reach goals	3.59	0.23	3.80	0.14	–0.20	–5.6%	<	0.2150	✗

Mean differences (absolute and relative %) and one-sided null-hypothesis p-values and rejection validation using the following significance level thresholds and symbols: Null-hypothesis rejected ✓: $p \leq 0.05$; marginally rejected ~: $0.05 < p < 0.2$; non-rejected ✗: $p > 0.2$.

Table 5. INCODE Rubric 5 – Highest ranked competences in CBI vs. PDP

	CBI		**PDP**	
Rank	**Competence**	**Score**	**Competence**	**Score**
1	24 – I am able to work in multicultural environments	4.56	24 – I am able to work in multicultural environments	4.57
2	23 – I am able to work in multidisciplinary environments	4.53	14 – I listen to teammates	4.43
3	4 – I evaluate the advantages and disadvantages of actions	4.53	23 – I am able to work in multidisciplinary environments	4.39
4	10 – I persistently pursue the goals	4.41	16 – I collaborate actively	4.29
5	14 – I listen to teammates	4.34	21 – I apply ethical values	4.29

5. Discussion

As seen in the results section, the only relevant differences were observed in the first dimension, Individual Competences. Among this group of skills, for competence number 3 "*I present new ways to implement ideas*", the difference is 0.31 (7.5%, p = 0.005) towards CBI. Number 4 "*I evaluate the advantages and disadvantages of actions*" displays a difference of 0.45 (9.9%, p = 0.003) also in favor of CBI. Number 10 *"I persistently pursue the goals*", has also a difference in favor of CBI of 0.28 (6.4%, p = 0.0036) and number 11 "*I take daring yet reasonable risks*" has a difference of 0.46 (11.7%, p = 0.01) for CBI, being the biggest difference.

At some distance, competences 1, 5 and 7 have non-negligible differences: Number 1 "I present ideas that are suitable for the task" displays a positive difference of 0.19 (4.4%, p = 0.104), number 5 "I identify relationships among different components of the task" has also a positive difference of 0.24 (5.7%, p = 0.104) and competence number 7 "I use available resources ingeniously" gives a difference towards CBI of 0.31 (7.7%, p = 0.087). All of them, mainly the first 4, have a strong innovation and entrepreneurship character, while most of the competences of dimension 2, Interpersonal competences, are close to the generic Teamwork and Leadership competences. The one with the lowest p-value and a non-negligible difference of 4.9% towards CBI (competence 18, "I take initiatives") could also be considered closer to the innovation & entrepreneurship character. Finally, competence number 21, from the Networking dimension "*I apply ethical values*" is the only one with a slightly significative difference in favor of PDP, with –0.29 (–7.1%, p = 0.083).

It is worth highlighting that the answers to the survey reflect the self-perception of the students from CBI and PDP. It is, of course, related with what they are taught and with the type of projects and methodologies used during the courses. But both groups are aware of participating in a singular course, which is different of almost all the other courses they enroll to. CBI is certainly a singular course, but PDP as a mandatory course is also non-so-common in the south of Europe.

Nevertheless, exploring the seemingly paradoxical results in the case under study, for example, PDP students do not receive specific classes on creativity. Surprisingly, PDP score in competence number 2 *I present creative ideas* is slightly higher (3.86) than CBI (3.75), where they follow a Design Thinking [24, 27] process with dedicated classes to creativity and ideation. This higher perception about creativeness of PDP students could be due to the fact that they work in groups composed only by engineering students and having more degrees of freedom than in the regular courses. On the other hand, CBI students work in multidisciplinary teams, composed by designers, engineers and MBA students. Thus, CBI engineering students, although being trained in creativity techniques and participating in creative tasks, compare themselves with people more trained in creativity skills, acknowledging that they might not be as creative as the other disciplines' students. This could partially be a result of what is known as the Dunning Kruger effect [30]. It is a "cognitive bias whereby people who are incompetent at something are unable to recognize their own incompetence. And not only do they fail to recognize their incompetence, they're also likely to feel confident that they actually are competent" [31]. This effect is produced due to people's performance perception is based partly in their preconceived notions of their own skills. The same Dunning Kruger effect might explain competence 20 and 23 results. Thus, it is worth to highlight that for this type of self-perception studies it would be good to complement them with other methodologies, as they could be influenced by a biased performance perception due to the fact that students are not experts and not fully aware of the total depth of knowledge in the field of study.

Derived from the lack of multidisciplinarity and working with like-minded people (only engineers), might be the reason behind for competence number 20 *I face conflicts with flexibility to reach agreements* to perform better in PDP (4.02) than in CBI (3.94). Given that in CBI the mindsets and backgrounds of the team members are so different, the way to approach and solve problems or conflicts is also very different, being not so easy to reach agreements and having to learn the language and mindset of the others.

Speaking specifically about multidisciplinarity, when scoring competence number 23 *I am able to work in multidisciplinary environments*, it is remarkable that for PDP is the third highest ranked competence (in CBI is the second). This is probably due to the fact that most PDP projects involve ICT engineering students from different minors (Networks, Communication Systems, Electronics). While the differences among them are really small, they perceive the experience as multidisciplinary because it is the only course in which they mix together.

About the neutral differential response in the networking competences, while CBI students have to find contacts and perform interviews with relevant stakeholders (e.g., CERN scientists, UN agencies in Geneva, top staff members in the industry, . . .), PDP students have also contact with external institutions (staff at hospitals, mid-level company representatives, project managers, city-council officers, . . .). Although the level and intensity of the contacts is different, both have the perception of having reached a satisfactory level of skills and certainly have improved them at the end of the projects.

Finally, it is worth mentioning the awareness of ethical values for both courses shown in competence number 21 "*I apply ethical values*". While the score is higher in PDP (4.29) than in CBI (4.00) (difference –7.1%, p = 0.083)it is probably due to that in PDP, decisions are mainly based on "cold" business or technical facts because the topics of the projects are real companies challenges with engineering focus (i.e., developing a sensor for 3D printing machines). They are also asked to perform a social, environmental and economical sustainability analysis of their project, following the directions given in a specific seminar about the topic, so they are aware about covering the issue although they do it in a quite superficial way. On the contrary, in CBI they work fully immersed in social challenges, with way more "human" implications and putting the students in contexts of also challenging their values when developing the project (i.e., access to water in rural Ghana), and their self-perception is similar and even lower.

Comparing the overall aggregated answers, the total average score of CBI is 4.09 and for PDP is 4.03. The difference between the two means is only 0.06 representing only a 1.5% in favor of CBI. The p-value is 0.06, in the borderline of rejecting the null-hypothesis, and the very small difference is almost significative probably due to the reduction of the standard error due to the big amount of aggregated answers, so we cannot take it into account.

6. Conclusions

As general conclusions we would highlight that both courses gave as result a good self-perception of the learning outcomes in the innovation-related skills, according to the results of the INCODE surveys, with all individual means above 3.5 out of 5 and being the overall mean of the aggregated results of 4 out of 5 in both groups.

Given the different approaches and teaching methodologies between CBI and PDP courses, very different outcomes were initially expected. Having one group focusing almost purely in engineering and technical projects (PDP) and the other one focusing on innovation projects with a wider perspective (CBI), with specific training sessions in broader innovation competences like user research, ideation, creativity, business modeling and entrepreneurship, the differences obtained with the INCODE Barometer are not as big as might be expected. The differences found between CBI and PDP groups are small and only moderately deviated towards CBI (4.6%) in the individual competences dimension. Although teachers and supervisors have the opinion that the learning outcomes of CBI students in innovation-related skills are higher than the PDP students' ones, this difference is small in the self-perception of students.

This may be due to the fact that the PDP students (only engineers) do not have a reference of students of other disciplines with higher skills for comparison, and do not have to face the same kind of conflicts than the CBI students. Thus, we can conclude that in terms of improvement of self-confidence, these types of courses contribute significatively with independence of the scale, mix of students and type of projects. The common features are teamwork, contact with the real world, interacting with stakeholders that are external to the institution, and some kind of multidisciplinarity, together with the feeling of carrying out a singular experience.

As final conclusions, we would say that despite the intensity and breadth of the project-based and experiential learning experience, it is worth to develop these types of courses to enhance self-confidence and self-perception on innovation competences on the students. Also, that although the INCODE Barometer is one of the few available tools, using questionnaires like this one to measure the innovation skills has the risk of biasing the answers by the sole reference to the skills made in the statement of the questions. An alternative or complementary methodology would be the qualitative analysis of final reports and reflection documents or the interviews to the students.

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DEVELOPING INNOVATION COMPETENCES IN ENGINEERING STUDENTS: A COMPARISON OF TWO APPROACHES

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Abstract

The gap between industry needs and engineering graduates' competences is being tackled by project-based courses, which also help to develop key innovation competences to address current societal challenges. Nevertheless, there is limited understanding about what innovation competences are developed through the different types of project-based courses. 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. The traditional project-based course demonstrates better results in Planning and Managing Projects. Creativity, Leadership and Entrepreneurship are more developed through a challenge-based approach combined with Design Thinking.

Keywords

Project Based Learning, Challenge-based Education, Innovation competences, Design Thinking, Multidisciplinary Education

Introduction

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, emphasize 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 et al. 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 challenge-based 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 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 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 analyzing 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.

Theoretical framework

Innovative behaviors may be learnt, and this learning should be based on experience and experimentation incorporating real-world experiences into the engineering curriculum (Chell & Althayde, 2009, Shuman et al., 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, et al., 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, CDIO and ENAEE – EUR-ACE®), with emphasis on innovation competences. In addition, the most exhaustive studies in Europe on innovation competences were reviewed: INCODE, FINCODA and NESTA. INCODE (Watts et al., 2013, 2014) focuses on higher education, while FINCODA (Marin-García et al., 2016) is meant to be applied in companies or other organizations. FINCODA was created as a new innovation competence model that complements and extends the existing ones (previously analyzing more than 12 innovation competence models). NESTA (National Endowment for Science, Technology and the Arts of United Kingdom) developed a set of innovation competences and a tool to measure them after a broad literature review and extensive testing in United Kingdom (Chell & Althayde, 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, 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.

Current research stresses an experiential learning approach, where the participants go through the key stages of innovation, moving from the concrete and abstract worlds (Beckman & Barry, 2007), in an environment with diverse teams. As Fixson (2009) states that "If innovation is understood as a process of inventing and commercializing new products and services, as a process that incorporates activities from multiple disciplines, and as a process that follows more heuristic than algorithmic rules, then perhaps this process can be taught in an interdisciplinary setting with a strong experiential emphasis, such as product design and development".

Within these experiential learning approaches, the 5th standard of the CDIO initiative (Conceive-Design-Implement-Operate, www.cdio.org) (Crawley et al., 2014), states the convenience of including two or more design-implement experiences in the engineering curricula, including one at a basic level and one at an advanced level. Adhered institutions usually have even more than two, concluding in a capstone project in the last year of engineering bachelor. They have evolved from "made up" projects created by faculty members, to product development projects with real industry challenges sponsored by companies or institutions (Dym et al 2005). These types of projects contribute to developing competences like teamwork, problem solving or communication, among others (Sayrol et al., 2015, Bragós et al., 2010).

It could be said that product development projects have traditionally trained the engineers to develop technical solutions rather than to innovate. Following OECD's definition of innovation, engineering student projects tend to be more inventions than innovations, as in general they lack sufficient considerations regarding the implementation of the solution from a value generation and value capture perspective. This contributes to the gap perceived by the industry and highlights the need to create educational strategies to develop innovation competences in engineering students that meet industry needs, but also match those key innovation competences identified by institutions.

Challenge-based learning is offered as the model that takes the best of problem-based learning, project-based learning and contextual teaching and learning while focusing on real problems faced in the real world (Johnson et al., 2009). Challenge-based learning, as defined by Malmqvist et al. (2015) is "a learning experience where the learning takes places through the identification, analysis and design of a solution to a sociotechnical problem. The learning experience is typically multidisciplinary, takes place in an international context and aims to find a collaboratively developed solution, which is environmentally, socially and economically sustainable". Challenge-based learning can be seen as an evolution of project-based learning but with a few differences, such as for example starting with large open-ended problems, training of self-awareness and self-leadership and entrepreneurial mind-set. The unique idea of challenge-based learning is that problems are relevant and with global importance, related to sustainability, water, energy, poverty, etc. Also, a differential aspect is the "call to action" that goes beyond the classroom, inviting the students to have an impact on the society with their projects (Malmqvist es al., 2015).

Working with open-ended problems in a more dynamic process (compared to design-build-test projects), shifting the focus from a technical problem to a societal problem, and requiring multidisciplinary knowledge poses challenges both for faculty and students involved in challenge-based learning. This approach raises the level of ambition of engineering education, going beyond the technical arena into the socio-technical domain developing competences like multidisciplinary teamwork, decision-making, communication and leadership (Malmqvist es al., 2015).

Design Thinking has been widely recognized for effectively dealing with the high levels of uncertainty involved in challenge-based projects. It is defined by Tim Brown (2008) as "a human-centred approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success". This innovation approach emphasizes people behaviors observation for detecting needs, multidisciplinary teamwork, quick and early visualization and prototyping of concepts to test them iteratively during the process. Design Thinking is for innovation early stages (Carr et al., 2010) and does not replace professional design or engineering (Charosky et al., 2018). It complements and reinforces the initial phases of innovation.

In summary today's systems and problems are progressively larger and more complex, and problems cannot be solved by applying a technical solution alone, as societal, rather than technical issues play a bigger role Lehman et al. (2008). This has shifted (or is shifting) educational strategies from the traditional paradigm with a discipline-oriented, lecture-centric and technical knowledge-based to a new interdisciplinary, student-centric and contextualized, with a complex understanding of technological knowledge. Engineers today need to have skills for interdisciplinary cooperation, communication skills, project management abilities and life-long learning abilities (Lehman et al., 2008). However, getting to this cross-disciplinary and contextual knowledge, integrating comprehension and skills from diverse disciplines is challenging and require innovative ways to approach education.

Empirical Setting

Once identified the innovation competences for engineering graduates and the two suitable and prevalent learning approaches for developing them, we aimed to analyze, 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 analyzed two courses developed at ICT engineering at Technical University of Catalonia (UPC): PDP course (Product Development Project) and the CBI course (Challenge Based Innovation).

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- 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) 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-of-concept 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 workpackages 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 of PDP), a course with a challenge-based learning approach (Malmqvist et al., 2015) combined with Design Thinking methodology (Brown, 2008, 2009, Ratcliffe, 2009).

Challenge Based Innovation (CBI) 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 IdeaSquare at CERN, one of the nodes of the Aalto Design Factory Global Network (DFGN). 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 & 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 (2015).

As observed in Table 2, the main differential aspects of these courses are the pedagogical method (Project-based vs. Challenge-based), the innovation method (NPD vs. Design Thinking), the team composition (single disciplinary vs. multidisciplinary) and the learning outcomes. Regarding the latter, it is interesting to highlight that even both courses learning outcomes mention some innovation competences, PDP does mention innovation as a learning outcome, while CBI does not. Also, PDP focuses more on project management, engineering design and implementation and CBI focuses more on ideation and validation through prototyping and testing with users.

Methodology

Out of the six different methodologies proposed by Prus & Johnson (1994) to assess professional skills in students, "measures of attitudes and perceptions" was chosen for this research. More specifically, self-reports named reflection documents in these courses, produced by students as part of the final deliverables of both courses and portfolios (projects) were analyzed and compared. Bandura (1982) found that reflective essays written by students can be a good predictor of design performance, as self-efficacy (belief in one's own abilities toward a given task) play a fundamental role in effectively executing innovation.

As the research aims to analyze whether an educational practice makes a difference (CBI course vs. PDP course) for developing innovation competences, we used an experimental design research approach. As described by Creswell (2012), experimental designs (also known as intervention studies or group comparison studies) are “procedures in quantitative research in which the investigator determines whether an activity or materials make a difference in results for participants”. Our research assesses the impact by having one group going through a set of activities (an intervention, in this case CBI course) and with-holding these activities from another group (in this case the PDP group).

Strictly speaking, as we are not able to address some of the key characteristics of “true experiments” as defined by Cohen et al. (2012), we must refer to a quasi-experiment. One of the characteristics that we don’t have and would be desirable is a pretest of the groups to ensure parity. We have run a post-test only and a comparison of the results of the two groups.

Research is based on a qualitative analysis of “personal reflection documents” and project results produced by the students as part of their deliverables when finishing the courses (both CBI and PDP). In these documents, students were asked to reflect on their process, lessons learnt, project’s results and future/next steps of their projects through general and broad questions. In neither case (PDP nor CBI) students were asked specifically to reflect on innovation competences and/or their perception about them.

To analyze these materials, a content analysis was followed, described by Weber (1990) as a process “by which the many words of texts are classified into much fewer categories” with “strict and systematic set of procedures for the rigorous analysis, examination and verification of the contents of written data” (Flick 1998). In summary, a mixed methods research design was followed for collecting, analyzing, and “mixing” both quantitative and qualitative methods in a single study to understand the research problem (Creswell & Plano Clark, 2011).

Participants and sampling

The strategy followed to define the sample to study is a purposive sampling, defined by Cohen et al. (2007) as selecting the cases based on their “typicality or possession or characteristics being sought”. We aim to have homogeneous samples (Patton, 1990), with the purpose to describe two particular subgroups in depth: students that follow PDP vs. students that follow CBI course.

The characteristics that we were looking for were students who went through a project-based course working on real projects for companies, external institutions and/or social challenges aiming to develop a technical solution and a prototype.

In this case, as described previously we analyzed results and compared two groups of students of Telecom Engineering from Technical University of Catalonia:

- Students that have taken the capstone project course PDP (Product Development Project), called Advanced Engineering Project (AEP) from 2015 to 2019 following a classical project management approach.
- Engineering students that have taken the CBI (Challenge Based Innovation) course from 2015 to 2018 following a challenge-based education approach using Design Thinking.

The population of interest can be fairly determined as all Telecom students must take one course or the other.

PDP teams are composed of 9-12 engineering students only. In CBI there are 2 engineering students in each multidisciplinary group of 5-7 people. The proportion of female engineering students in PDP and CBI is 17%, slightly below Technical University of Catalonia 25% average (Farreras, 2019). Age (20-22 years), cultural (almost all Catalan) and socio-economic background is pretty homogeneous in both courses, with the only possible bias being in CBI the need for affording the cost of 3 trips to Geneva for the CERN periods.

Both courses have a similar student's assessment: a team mark (50% is based on the process and 50% on the outcome (technical performance and complexity, solution innovativeness, prototype, final report and presentation), plus an individual performance modulation given by the supervisors and by peer assessment. Also, both courses have at least, a weekly coaching hour with several faculty members.

Sample size

Although there is not a fixed answer in what is the minimum number of participants or cases to define a sample for quantitative, qualitative study or mixed methods, literature suggests a rough estimate for educational research of approximately 15 participants in each group in an experiment and 30 participants for a correlational study for a statistical procedure (Cresswell, 2012, Cohen et al., 2007).

As the number of cases to be analyzed are in both cases (PDP and CBI) more than 30 personal reflections and project results, we could say that it is enough to withdraw relevant conclusions.

Data collection

All personal reflection documents delivered and final project reports within the period researched were collected, being a total of 77 documents analyzed with 38 from PDP and 39 from CBI (Table 3). The reason of having less reflection documents in the first years for PDP is that only projects with external stakeholders (companies or institutions) have been chosen for the analysis. These were gradually increased in the following years.

Data analysis

The analyzed data are the 77 reflection documents produced by the students, with the aim of identifying mentions, insights, conclusions, keywords and learning outcomes related to innovation competences through content analysis and data coding.

The sought data in the documents was evidence (direct or indirect) of innovation competences discussed in research and literature previously defined: CDIO, ABET, ENAEE – EUR-ACE®, NESTA, INCODE and FINCODA projects. The competences identified in the literature review (Table 1) were merged and structured into a framework (Table 4) that synthetizes and condenses all the competences into 8 themes or categories composed of 26 innovation competences. The framework was developed through an iterative process of analysis and coding of the documents done separately by the authors, later discussing its validity and utility, evolving it into the final set of themes and codes innovation competences (derived from literature review) and used for the analysis of the documents (Table 4).

The process followed for the content analysis was the one described by Tesch (1990) and Cresswell (2007). Using a convergent approach, the coded qualitative data was descriptively analyzed and the frequency of occurrence of these codes was counted (Cresswell, 2012).

Finally, a total of 1665 segments were coded, 790 (47%) in 38 documents from PDP and 875 (53%) in 39 documents from CBI.

To analyze the data, the software for text analysis MAXQDA was used, as it enables to combine both qualitative and quantitative procedures. It allows identifying specific words and expressions as codes, organizing the codes by themes and counting and classifying them. The analysis consisted on reviewing all the texts imported in the software and manually marking all expressions that would have the same meaning than a given code under its category.

Results and discussion

This section has been split in two parts: in Results, there is first a neutral description of the numerical results of the code frequencies, commenting the content of the tables and the figures (in the online version) and the specific results within each group of innovation competences. Subsequently, in the Discussion subsection the authors' interpretation of the results are described.

Results

When analyzing the groups of innovation competences or themes, it is observed that both courses CBI and PDP help to develop all innovation competences as shown in Table 5. Nevertheless, each course clearly emphasizes some competences over others as observed in Figure 1 & Figure 2. Planning and Managing a Project, Leadership & Entrepreneurship and Creativity are the three groups of innovation competences with the biggest differences. On the other themes/groups of innovation competences the differences are not as big in a general view, but when looking at specific competences (codes) within the themes great differences can be found as observed in Table 5. It is also observed that Experimentation & Knowledge Discovery, Teamwork and Personal & Professional Skills are the competences with most coded segments in total. Table 6 shows where are the bigger percentages of coded segments, to visualize which innovation competences are more present in students' reflection documents in each course.

On a deeper level of detail, as shown in Figure 3, analyzing the percentages of specific innovation competences we can observe big differences in PDP and CBI. While in PDP the bigger percentages of coded segments can be found in Organization (13%), Technical solution/technology (12%), Self-efficacy (10,1%), Coordination (9,7%), Problem Solving (6,8%) and Communication (6,2%); in CBI the bigger percentages are in Multidisciplinarity (11,7%), Self-efficacy (8,2%), Uncertainty management (7,4%), Networking (6,4%), Technical solution/Technology (6,2%) and Idea generation (6,1%).
In general, it could be said that CBI has a more balanced distribution of innovation competences development, while in PDP it is more concentrated towards some specific engineering related competences. Also, as shown in Table 6, CBI shows better results in Creativity, Leadership & Entrepreneurship, while PDP demonstrate better results in Planning & Managing a Project and Experimentation & Knowledge discovery. Teamwork, Impact and Networking have smaller differences, but with better results towards CBI and results in Personal & Professional skills are equal in both courses.

In the following paragraphs, the results within each of the 8 innovation competences groups are presented in depth. Table 7 highlights some quotes related to each innovation competences group.

More specifically, the innovation competences related to Planning and Managing a Project (Planning, Organization & Time Management) are which in average show the biggest difference between the two courses. Within the three competences related to Planning and Managing a Project, the biggest difference found is in Planning, with 36

(97%) mentions in PDP and only 1 (3%) mention in CBI. The differences are also big in Organization, with 103 (86%) in PDP and 17 (14%) in CBI, and in Time Management, with 36 (75%) in PDP and 12 (25%) in CBI.

Leadership & Entrepreneurship, composed by the competences Entrepreneurship, Leadership/Initiative, Energy and Risk-propensity, is the second set of innovation competences with the major difference observed, being 16% in PDP and 84% in CBI in average. The total number of coded segments is163, with 117 for CBI and 46 for PDP (Table 5). No evidence or mentions of entrepreneurship are found in PDP and 21 coded segments are found in CBI. Regarding leadership, even though that PDP teams are required to define a project leader (while CBI teams don't), there are more findings in CBI related to this competence (50 coded segments in CBI vs. 13 in PDP). Regarding Energy, there is a small difference, with 44 coded segments for CBI (57%) and 33 for PDP (43%). Finally, there are only 2 mentions to Risk-propensity found in CBI.

Creativity, containing the competences of User awareness, Uncertainty management, Idea generation and Design Thinking, is where is found the third biggest difference of the research (Table 5), with 22% in PDP and 78% in CBI, from a total number of coded segments of 237 (73 for PDP and 164 for CBI). Within this set of innovation competences, idea generation is where the more relevant difference is identified with only 5 mentions in PDP and 53 mentions in CBI. Design Thinking has 9 mentions in CBI and no mentions in PDP (it was not explicitly included in this course during the analyzed period). Even though that PDP is not taking a declared user-centered innovation approach, the difference in the level of user awareness is not as high as in other competences (21mentions in PDP vs. 37 mentions in CBI).

Another big learning in this type of projects is uncertainty management, with little differences found between CBI (47 coded segments) and PDP (65 coded segments). Even though in PDP both requirements and outcomes are more defined, students struggle in both courses when they don't have an exact specifications of what to do, as observed in the quotes from Table 7.

Innovation competences' learning related to impact (Business sense, Social impact and Sustainability) are also having a relevant difference between PDP (35%) vs. CBI (65%), out of a total number of mentions of 81, with 54 for CBI and 17 for PDP (Table 5). Even though the total number of mentions related to Impact is not so big (81). The main difference is in Social Impact with 29 mentions in CBI vs 8 mentions in PDP. Regarding sustainability there are only 3 mentions in CBI and 2 mentions in PDP. And regarding business sense, there are 39 mentions, with a little difference in favor of CBI (22) vs PDP (17).

The total number of evidence found in the analyzed documents related to Networking is small (79) compared to other themes (Table 5). It has more weight in CBI (71%) than in PDP (29%). In most cases related to contacts with stakeholders and companies.
One thing to highlight is the relationship with CERN in CBI, which is mentioned a total of 17 times in the 39 CBI personal reflections & project conclusions.

Overall, there is a small difference between PDP (41%) and CBI (59%) students' competences development within Teamwork (Communication, Coordination and Multidisciplinary) with a total number of coded segments of 306, 127 for PDP and 179 for CBI (Table 5). Specific mentions to coordination and communication are found with little more frequency in PDP students' analyzed documents (49 vs 33 for Communication and 77 vs 44 for Coordination). Nevertheless, the big difference is in the multidisciplinary competence. In CBI students' documents there are found 102 mentions to this competence, being the most mentioned topic by this course students. In PDP there is only 1 mention, and even it refers to multidisciplinary it is actually considering different engineering specialties. The fact that in CBI the teams are composed by students of three different institutions and different profiles (engineering, business and design) is highly appreciated by engineering students, as observed in the documents.

Within Experimentation & Knowledge discovery competences (Problem solving, Technical/Technology development, Investigation & Knowledge discovery and Experimentation) the difference found between PDP and CBI is 64% vs. 36% out of a total of 320 coded segments, with 189 for PDP and 131 for CBI (Table 5). Problem solving (54 in PDP vs 39 in CBI), Investigation & Knowledge discovery (20 in both PDP and CBI) and Experimentation (20 in PDP and 18 in CBI) are pretty well balanced in both courses as found in the analysis of projects' documentation and reports. The main difference is the fact that in PDP there is more evidence of mentions related to Technical/Technology development, being 64% (95) vs 36% (54) in CBI of a total of 149.

Regarding Personal and professional skills (Self-efficacy, Critical Thinking and Self-awareness for professional life), there is a very slight difference found on CBI (55%) respect to PDP (45%), with a total of 274 coded segments, 130 for PDP and 144 for CBI (Table 5). Competences related to Critical thinking (36 for PDP vs 24 for CBI) and Self-efficacy (80 for PDP vs 72 for CBI) are almost equally found in both courses' students, with a little more emphasis on PDP students. What makes the difference in this group is the competence defined as Self-awareness for professional life, which is more mentioned in CBI (77%) than in PDP (23%).

Discussion

Our research demonstrates that both learning methods are good educational strategies for developing competences and, explicitly, innovation competences in engineering education, but each strategy emphasizes some competences more than others. The big differences found in Planning and Managing a Project, Leadership & Entrepreneurship and Creativity are aligned with the initial hypothesis. But our study also revealed that as well as CBI, PDP greatly contributes to develop all other innovation competences to a relevant extent, according to the reflections reported by the students. Although the two engineering education strategies were a priori known to be successful in innovation competences development, it was considered worthy to perform this study. This is due to the fact that, after more than one decade of experience developing both kind of courses, it was observed that the PDP model is easily accepted by the engineering school faculty members as a natural way of providing a context closer to the engineering practice, while the challenge-based model finds more reluctancy to be accepted. So the study was intended to highlight the diferential benefits, although being both of them highly beneficial.

The major emphasis on Planning and Managing Projects competences in PDP might be due to the fact that in this course the focus is more on achieving a technical solution to a clearly defined industry problem from a company. Thus, students focus more on a traditional project management approach and on problem solving and technical/technology development. All emphasis is put into execution and not in exploration (Loch et al., 2006). Also, PDP has more demanding requirements for project planning and reporting, including bigger teams (9-12 people in PDP vs. 5-7 in CBI), which might influence this bias. This may be due to the fact that in PDP, the projects are techcnically complex and the teams are intentionally big, in order to force them to split in parallel workpackages and have to manage the subprojects and the system integration. Also, for the CBI course, the project plan is implicit in the Design Thinking methodology steps, and the students are asked to report the intermediate results with short presentations instead of formal reports.

The fact that Leadership & Entrepreneurship competences are more developed in CBI is probably due to that in most PDP projects the sponsors or clients pose very specific technical problems, with very concrete requirements of current business or industry needs. Thus, PDP students do not consider or need to employ entrepreneurship competences because they work on a technical solution within a very well-defined framework of an existing company. On the contrary, CBI students, even though they have project sponsors (yet not in all cases), are given challenges that are wide open and do not sit on short-term specific industry/company needs or requirements. This openness allows students a great freedom in the solution space (Rattcliffe, 2009), making it possible to develop solutions integrated (or to integrate) in existing companies' processes or creating hypothetical startups that would develop and market the solution.

The fact of having an external institution, either a company, a startup or any entity from outside the school proposing a challenge or project briefing provides a great sense of reality and develops a greater engagement and sense of responsibility in the students. It provides them a real practice in what could be typical projects they would face when graduating and start working at a company. On the other hand, if instead of having companies putting challenges, the framework is broader like the SDG-Sustainable Development Goals from UN (like in CBI), this brings another perspective and greater learnings and focus on the social impact of student's projects, as opposed to PDP where the focus is on a technical issue from the industry. Also, not having a "client" with clear requirements, allows the entrepreneurial spirit to naturally raise in the students. As what they develop is not for an existing company, and the solution they create has not an existing channel for going to market, the idea of creating a hypothetical startup that would market that solution is more likely to appear. On the contrary, in PDP like projects, the idea of building a startup only makes sense when the institutions are not the ones developing the product/service (as in the case of NGOs or hospitals) while in the projects stated by industrial or services companies, the students' business model is more likely an engineering consultancy.

Another relevant fact is that in CBI, UPC (engineering) students are exposed to business and entrepreneurship sessions from ESADE (business) professors. Also, having MBA students and designers in the same teams with the engineers and interacting together with other stakeholders, as it is likely the case in a real startup, has a positive influence in developing leadership and entrepreneurship competences. On the other hand, PDP students in general have interlocutors, both from the company and from the supervisors' side, that are technical staff and engineers. Probably that is why there is no evidence or mention of entrepreneurship in PDP, whereas there are 21 coded segments found in CBI. This is in line with the results discussed by Palomäki (2019), which demonstrated that CBI has a positive impact on the entrepreneurial intentions of the students participating in this course. Regarding leadership, even though that PDP teams are required to define a project leader, there are more findings in CBI (where this leader figure is not formally chosen but naturally appears) related to this competence. As in this type of challenge-based course the level of uncertainty is higher (Malmqvist et al., 2015) and tasks and deliverables are less defined, students' leadership is triggered as they need to find the answers and define what to do by themselves.

Factors like learning the Design Thinking process in CBI with its dedicated time slots for idea generation and iteration, as well as specific sessions with tools and methodologies for ideation definitely make a difference in developing Creativity competences in this course. Furthermore, Impact innovation competences are more developed in CBI possibly because of having more emphasis on social impact due to focus, especially since in the last years the challenges have been framed around the United Nations Sustainable Development Goals (SDGs, 2015) as mentioned above. The students, therefore, have to reflect more on the end-to-end implications of the solutions they are developing. Also, regarding to business sense, the fact of being in contact with MBA students and having specific classes on this from ESADE clearly make a difference. On the other hand, the PDP course students usually see the business model as a side topic of the project.

The multidisciplinary experience (engineering, design & business) has proven to be a successful tool to enhance the innovation and entrepreneurial skills in engineering students but due to its cost (teaching staff involved, dedicated spaces, ...), it probably cannot be scaled to all the students. But the methods developed, and lessons learnt can be partially applied to capstone projects and even to standard courses in engineering education. Thus, it is highly recommended to introduce some degree of multidisciplinary in project-based courses. Students perceive this as a "real life professional experience", as they are aware that in this type of teams is how they will really work when they graduate, interacting with people from different disciplines.

It is important highlighting that one of the limitations of this research is that all the data analyzed are post-test, without having a starting assessment. Although it was not possible in our study, for further research it would be recommended to have a pre-test and post-test, in order to compare student's innovation competences before and after the courses. This would give a more precise measurement of the impact on innovation competences of both type of courses. Also, it is important to mention that by default all students should initially take the PDP project course, but the CBI course is offered as an alternative way of doing it. For being accepted to CBI they need to proactively opt for it, and they have to present their grades and a motivation letter. This poses a potential risk for the study, as CBI students may already have a certain bias or motivation to better develop innovation competences versus PDP students. This risk is also mitigated as PDP course runs twice a year (Fall and Spring terms) and CBI only runs once a year (Fall term), being that students taking the project-based course in the 2nd semester cannot opt to attend CBI. In addition, students enrolling in CBI acknowledge that their initial main motivation is the relationship with CERN.

Even though this research was focused on engineering education and only ICT engineering students' projects results were analyzed, we could argue that the conclusions on experiential learning approaches for developing innovation competences could be applied to any field (not only in engineering). As discussed in literature (Marí-Benlloch, 2017), they are transversal competences that any future graduate and the society would benefit from. Being ICT an innovation driver in any field, due to the digitalization trend, with most innovation projects in any field including an APP, AI or IoT solutions, the fact of working with ICT engineering students gives an extra degree of value and reality to the projects.

Conclusions

Our study summarized the innovation competences needed for engineering students and confirms that experiential learning experiences like project-based and challenge-based education combined with Design Thinking are methods that successfully contribute to developing the aforementioned innovation competences, answering our initial research questions.

We can say that regardless of the effort and resources needed to develop these experiential learning experiences, it is worth to promote these types of courses (either project-based or challenge-based) to develop innovation competences on engineering students much needed by the industry and the society. We need people trained to innovate, to face the huge challenges ahead of us, like climate change, access to water, poverty among others, that are well summarized in the SDG from UN. Following a traditional project-based course is better suited for developing Planning and Managing a Project related innovation competences and Experimentation & Knowledge Discovery. For developing Creativity and Leadership & Entrepreneurship competences, a challenge-based course combined with Design Thinking approach would be a better choice. Finally, both methods are similarly appropriate for developing all other innovation competences related to Teamwork, Impact, Personal & Professional Skills and Networking.

Although a full immersion in Design Thinking like CBI probably cannot be extended to all engineering students due to the high number of resources required (trained teaching staff, dedicated coaches and spaces, time and calendar restrictions for the multidisciplinary projects), a basic knowledge of the basics of these user-centric innovation approach would be very beneficial for engineering students. Nevertheless, there is a tradeoff that needs to be well balanced: the dedicated time for direct contact with users improves the creative part (needfinding, ideation) but reduces the time for designing, implementing and testing complex solutions and the associated learning outcomes. Then, with limited time and resources, engineering educators should choose between focusing more on entrepreneurial skills or technical skills. The (not so) standard PDP courses would provide tools to get the learning outcomes of analytical design and more time for developing the technical solutions, but missing the value of empathizing with users, deeply understanding needs and penalizing creativity.

A possible logical scenario could be to dedicate one semester to a CBI like course and afterwards a PDP like course with the same challenge, in which the technical implementation of the idea generated and validated in the first one is performed. Nevertheless, the complexity and abstraction ability needed to perform CBL is higher than the one needed to follow a PDP course. Then, the reverse order would be more suitable, although having the same challenge would not be needed in that case. From our findings, the only evidence is that both kind of courses provide learning outcomes on some innovation-related competences (as expected and known beforehand). But there is a clear advantage for developing Creativity and Leadership & Entrepreneurship competences using a challenge-based course model combined with Design Thinking approach, in which the multidisciplinarity and user approach are key factors. Therefore it is worth to provide this kind of experience to the engineering graduates.

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Declaration of interest statement

The authors do not have conflicts of interest about this research.

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Tables with captions (on individual pages)

SOURCE	PROPOSED SET OF INNOVATION COMPETENCES	
INCODE The Innovation Competencies Development project (Watts et al., 2013, 2014)	• Individual: creativity and critical thinking • Network: networking and impact	• Interpersonal: teamwork and leadership
FINCODA Framework for Innovation Competencies Development and Assessment (Marin-García et al., 2016)	• Creativity • Critical thinking	• Intrapreneurship: initiative, teamwork and networking
ABET Accreditation Board for Engineering and Technology (ABET, 2017, Shuman et al., 2005)	**Process skills:** • Communication • Teamwork • Ability to identify and solve ethical dilemmas	**Awareness skills:** • Social and global factors impact understanding • Contemporary issues knowledge • Ability for lifelong learning
CDIO Syllabus v2.0 Statement of Goals for Engineering Education (Crawley et al., 2011)	**Competences related with innovation:** • Analytical reasoning and problem solving • Experimentation • Investigation and knowledge discovery • System thinking • Teamwork	• Communication • External societal and environmental context • Enterprise and business context • Leading engineering endeavors • Engineering entrepreneurship
ENAEE – EUR-ACE® European Network for Accreditation of Engineering Education	• Knowledge and Understanding • Investigations	• Engineering Practice • Making Judgements • Communication and Team-working
NESTA National Endowment for Science, Technology and the Arts of United Kingdom (Chell & Althayde, 2009)	• Creativity (imagination, connecting ideas, tackling and solving problems, curiosity) • Self-efficacy (self-belief, self-assurance, self-awareness, feelings of empowerment, social confidence) • Energy (drive, enthusiasm, motivation, hard work, persistence and commitment)	• Risk-propensity (a combination of risk tolerance and the ability to take calculated risks) • Leadership (vision and the ability to mobilize commitment)

Table 1 - Selection of innovation competences identified for the development of engineering education according to different standards

Course	Pedagogical method for innovation education	Innovation method	Team composition	Learning outcomes
PDP Product development project	Project-Based	NPD (New product development)	Single disciplinary (engineering students only)	• Project management and documentation • Specific disciplinary knowledge about the project topic • Practical design, implementation and operation skills • Generic skills learning outcomes: Innovation and entrepreneurship, Societal and environmental context, Communication in a foreign language (English), Oral and written communication, Teamwork, Survey of information resources, Autonomous learning, Ability to identify, formulate and solve engineering problems (Bragós et al., 2010)
CBI Challenge based innovation	Challenge-based	Design Thinking	Multidisciplinary (engineering, design and management)	• Develop highly futuristic, technologically feasible ideas that have the potential to challenge the status quo in socially and globally relevant human challenges. • Develop skills applying design thinking tools and methods and product design in a practical, real world project. • Develop skills in moving ideas into testable, tangible prototypes quickly. • Develop skills in interdisciplinary teamwork and communication. (Hassi et al., 2016)

Table 2. Course comparison: PDP vs. CBI

	PDP	**CBI**
Year	**Nº of reflection docs**	**Nº of reflection docs**
2015	3	9
2016	2	10
2017	15	10
2018	10	10
2019	8	-
TOTAL	**38**	**39**

Table 3 – Total number documents analyzed per year and course

1. CREATIVITY • User awareness • Uncertainty management • Idea generation • Design Thinking	2. PLANNING AND MANAGING A PROJECT • Planning • Organization • Time management
3. LEADERSHIP & ENTREPENEURSHIP • Entrepreneurship • Leadership/Initiative • Energy • Risk-propensity	4. TEAMWORK • Communication • Coordination • Multidisciplinary
5. IMPACT • Business sense • Social impact • Sustainability	6. PERSONAL & PROFESSIONAL SKILLS • Self-efficacy • Critical thinking • Self-awareness for professional life
7. NETWORKING • Networking	8. EXPERIMENTATION & KNOWLEDGE DISCOVERY • Problem solving • Technical solution/Technology • Investigation & Knowledge discovery • Experimentation

Table 4 - Innovation competences framework: themes and code system

	PDP		CBI		Total
	Nº of coded segments	%	Nº of coded segments	%	
CREATIVITY	**73**	**22%**	**164**	**78%**	**237**
User awareness	21	36%	37	64%	58
Uncertainty management	47	42%	65	58%	112
Idea generation	5	9%	53	91%	58
Design Thinking	0	0%	9	100%	9
PLANNING AND MANAGING A PROJECT	**175**	**86%**	**30**	**14%**	**205**
Planning	36	97%	1	3%	37
Organization	103	86%	17	14%	120
Time management	36	75%	12	25%	48
LEADERSHIP & ENTREPRENEURSHIP	**46**	**16%**	**117**	**84%**	**163**
Entrepreneurship	0	0%	21	100%	21
Leadership/Initiative	13	21%	50	79%	63
Energy	33	43%	44	57%	77
Risk-propensity	0	0%	2	100%	2
TEAMWORK	**127**	**41%**	**179**	**59%**	**306**
Communication	49	60%	33	40%	82
Coordination	77	64%	44	36%	121
Multidisciplinary	1	1%	102	99%	103
IMPACT	**27**	**35%**	**54**	**65%**	**81**
Business sense	17	44%	22	56%	39
Social impact	8	22%	29	78%	37
Sustainability	2	40%	3	60%	5
PERSONAL & PROFESSIONAL SKILLS	**130**	**45%**	**144**	**55%**	**274**
Self-efficacy	80	53%	72	47%	152
Critical thinking	36	60%	24	40%	60
Self-awareness for professional life	14	23%	48	77%	62
NETWORKING	**23**	**29%**	**56**	**71%**	**79**
EXPERIMENTATION & KNOWLEDGE DISCOVERY	**189**	**56%**	**131**	**44%**	**320**
Problem solving	54	58%	39	42%	93
Technical/Technology development	95	64%	54	36%	149
Investigation & Knowledge discovery	20	50%	20	50%	40
Experimentation	20	53%	18	47%	38
SUM	790	47%	875	53%	1665
N = Documents	38	38 (49%)	39	39 (51%)	77

TABLE 5 – Innovation competences themes and total number of coded segments and row percentages

	PDP	CBI	Total
CREATIVITY	**9,2%**	**18,7%**	**14,2%**
User awareness	2,7%	4,2%	3,5%
Uncertainty management	5,9%	7,4%	6,7%
Idea generation	0,6%	6,1%	3,5%
Design Thinking	0,0%	1,0%	0,5%
PLANNING AND MANAGING A PROJECT	**22,2%**	**3,4%**	**12,3%**
Planning	4,6%	0,1%	2,2%
Organization	13,0%	1,9%	7,2%
Time management	4,6%	1,4%	2,9%
LEADERSHIP & ENTREPENEURSHIP	**5,8%**	**13,4%**	**9,8%**
Entrepeneurship	0,0%	2,4%	1,3%
Leadership/Initiative	1,6%	5,7%	3,8%
Energy	4,2%	5,0%	4,6%
Risk-propensity	0,0%	0,2%	0,1%
TEAMWORK	**16,1%**	**20,5%**	**18,4%**
Communication	6,2%	3,8%	4,9%
Coordination	9,7%	5,0%	7,3%
Multidisciplinarity	0,1%	11,7%	6,2%
IMPACT	**3,4%**	**6,2%**	**4,9%**
Business sense	2,2%	2,5%	2,3%
Social impact	1,0%	3,3%	2,2%
Sustainability	0,3%	0,3%	0,3%
PERSONAL & PROFESSIONAL SKILLS	**16,5%**	**16,5%**	**16,5%**
Self-efficacy	10,1%	8,2%	9,1%
Critical thinking	4,6%	2,7%	3,6%
Self-awareness for professional life	1,8%	5,5%	3,7%
NETWORKING	**2,9%**	**6,4%**	**4,7%**
EXPERIMENTATION & KNOWLEDGE DISCOVERY	**23,9%**	**15,0%**	**19,2%**
Problem solving	6,8%	4,5%	5,6%
Technical solution/Technology	12,0%	6,2%	8,9%
Investigation & Knowledge discovery	2,5%	2,3%	2,4%
Experimentation	2,5%	2,1%	2,3%
SUM	100%	100%	100%
N = Documents	38	39	77

TABLE 6 – PDP and CBI Innovation competences percentages based on the total number of coded segments

Innovation competence	Examples of quotes
CREATIVITY •User awareness •Uncertainty management •Idea generation •Design Thinking	*"was an interesting experience…to explore different ways of thinking and learning how an idea is created and developed"* *"it is no bad for an engineer to be down to earth but he has to keep in mind his imagination is important too".* *"we had plenty of interviews with doctors and victims and, for sure, we learnt a lot from them"* *"a good engineer does not only have to know about the implementation, he also must think about the real demand of users"* *"bigger efforts should be put in providing the project with clearer specifications and benchmarks"* *"few things could be improved. The first of them is the excessive freedom we are given".* *"I have the impression we were never told in clear terms what the course was about or what we were expected to do" and "I started to like more and more this methodology although some phases were pushing me outside of my comfort zone".*
PLANNING AND MANAGING A PROJECT •Planning •Organization •Time management	*"we did it thanks to good planning and coordination"* *"there should be also a more important part in project management, which has proven itself to be the cornerstone of everything, and has been only given a quick look, and it could be an area of interest to some team members, more than the most technical part".*
LEADERSHIP & ENTREPENEURSHIP •Entrepreneurship •Leadership/Initiative •Energy •Risk-propensity	*"I took the lead on organizing what tasks we had to do and who was the responsible of performing those assignments"* *"One of the most interesting things I've learned during the course is how to make my voice heard and how to influence team decisions".* *"Once we continue the research and try a prototype with the costumer we already have, the idea would be to create a startup."* *"The role that I would like to play if we create a startup is not only in the technology part, I would like to take part in all the decisions made within the process and also when the company grows"*
TEAMWORK	*"we could have done better as a team is to communicate more often and more accurately between the different subgroups"* *"the team's weakness during the project was organization"* *"the fact of working with people from other disciplines gave me an insight of the real world that I couldn't have received from any other place"* *"before doing this project I thought that other disciplines were not as useful as my own. Now I can see that the part of engineering needs all the other disciplines as much as they need us in the process of building a company"*
IMPACT	*"Explaining how our engineering impacts over society and over the environment is something that always will be demanded by any entity"* *"We had the opportunity to verify that our knowledge and our ideas can have a positive impact in the world".*
PERSONAL & PROFESSIONAL SKILLS	*"I have learnt many things here that any theoretical course or lecture can't teach, and I feel much more prepared now for the real life, real projects and real work."* *"this project has taught me a lot of key skills that are crucial for the professional life"* *"we have learnt a lot from other branches which are in principle not taught in engineering and that surely they are essential in the professional world"* *"I have learned a plethora of things that I am sure will be very valuable for my future professional career"* *"the learning outcomes of the project are both very valuable and very sought in the professional world".*
NETWORKING	*"regarding the companies we met during the course, we are analyzing which of them are the best so as to purpose a partnership"*

	"working with such a good institution as CERN has made us build a very powerful contact network"
EXPERIMENTATION & KNOWLEDGE DISCOVERY	*"using Blockchain Technology we have successfully tackled the royalty distribution problem"* *"a complete architecture for the radar has been built and a display for monitoring the vital signs has been designed, which also include the heartbeat frequency, breath rate and alarms in case of tachycardia, bradycardia and apnea"* *"we have seen that one way to do an accurate design is to have a simple prototype that works and then to improve it".*

TABLE 7 –Innovation competences quotes examples

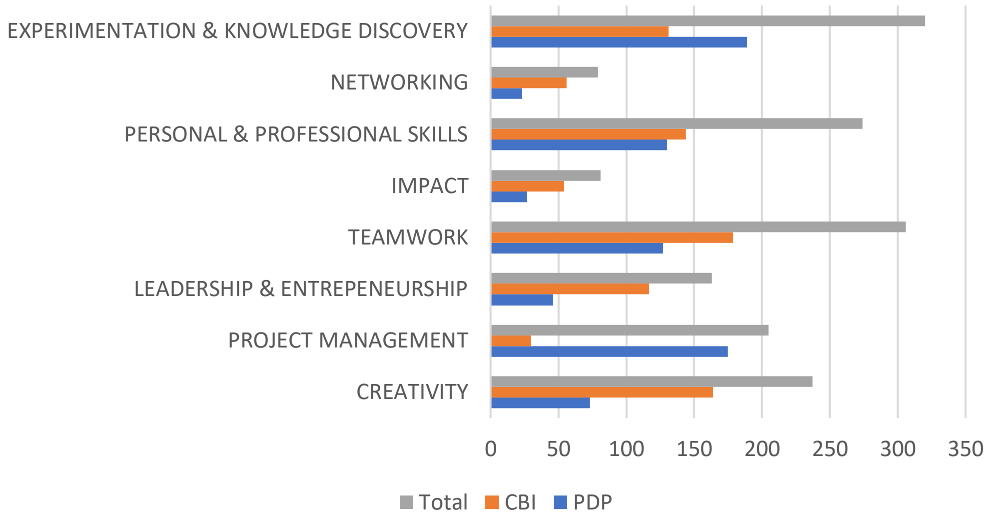

Figure 1. CBI and PDP total coded segments by innovation theme

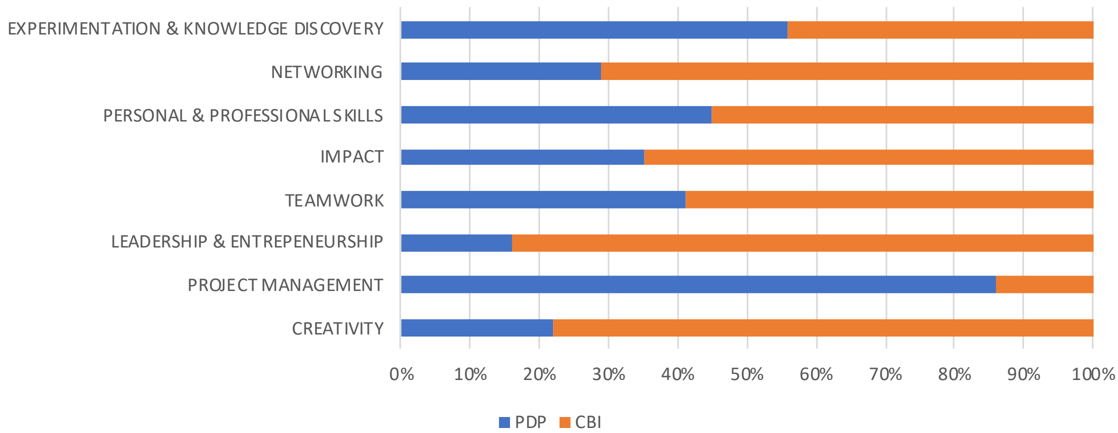

Figure 2. CBI and PDP total innovation themes coded percentages

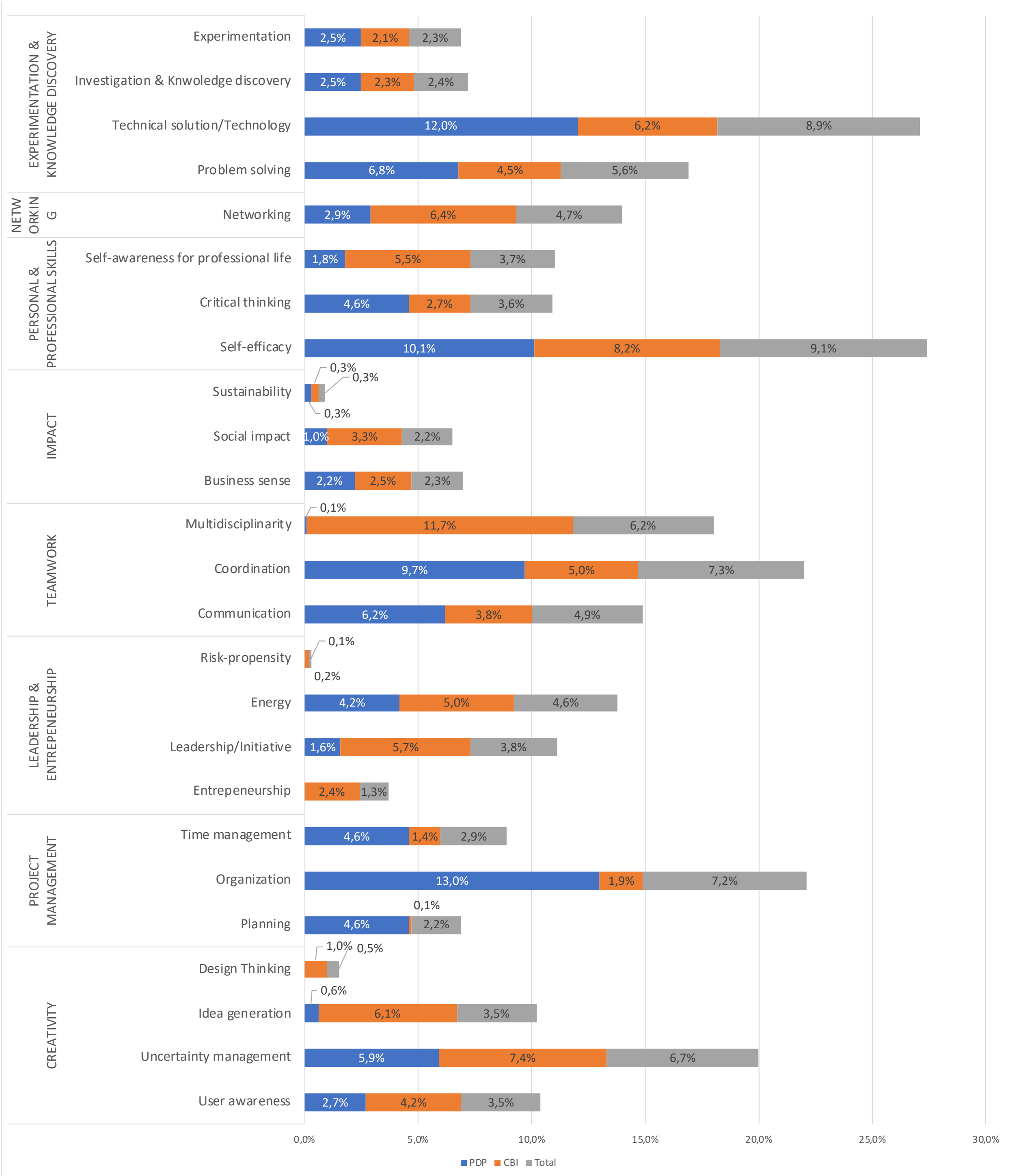

Figure 3 – PDP and CBI Innovation competences percentages based on the total number of coded segments

Biographical note

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170 conference papers. From the academic point of view, he is co-author of 3 textbooks and has taught in the field of analog electronics, instrumentation, sensors, biomedical engineering and engineering projects. Since 2009 he's the associate dean of academic innovation at UPC Telecom Engineering School (ETSETB-TelecomBCN), in charge of the implantation of the CDIO model for engineering education (www.cdio.org) and coordinator of the project-based subjects. He's currently sharing his research field with EER where he's been working in Remote Laboratories and Project-Based methodology and is currently working in Design Thinking methodology with multidisciplinary teams.
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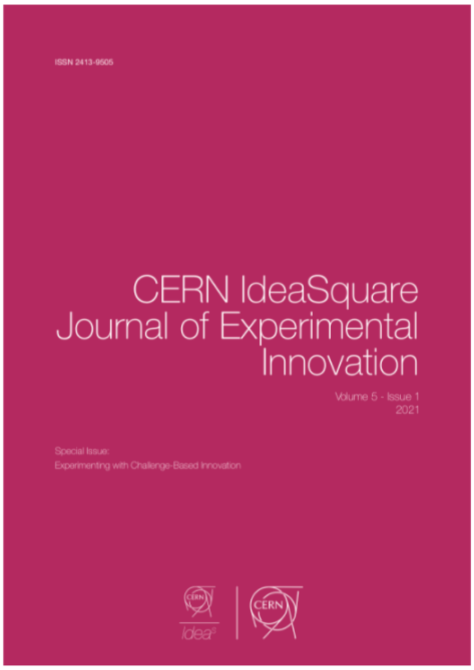

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ORIGINAL ARTICLE

Prototyping the future of learning: reflections after seven iterations of Challenge-Based Innovation (2014-2020)

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ABSTRACT

This article presents the reflections of a multidisciplinary team working on CERN's Challenge-Based Innovation (CBI) since 2014. These reflections on pedagogy and innovation are positioned at the intersection of experiential learning, design thinking and challenge-driven education. Drawing from seven editions of what has become "CBI Fusion Point," we present our story as an ongoing journey of experimentation with various formats and methods in response to broader shifts in education. Our article contributes to a better understanding of the characteristics and challenges that CBI-like programs pose and the infrastructure and support that they require.

Keywords: Challenge-driven education; experiential learning; design thinking; future of teaching creativity; innovation and entrepreneurship.

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INTRODUCTION

Higher education appears to be at a tipping point concerning its purpose, structure and content. Although scholars have long been raising concerns about the efficacy of college degrees in preparing graduates for the needs of the job market, there has been a significant increase in the volume and sense of urgency to increase the impact and relevance of academic institutions. There are several models and initiatives that suggest changes needed in educational paradigms for schools and universities to be more creative (Robinson & Aronica 2015), innovative (Christensen & Eyring 2011) and entrepreneurial (Etzkowitz, 2003).

There is a general understanding of what education should look like, but how to make this happen is less clear. While there is a plethora of toolkits with methods and techniques for teaching and enhancing innovation (see for example IDEO, Stanford D-school and NESTA), limited attention has been given to their repurposing for learning within higher education organizations (Beckman & Barry 2007). Relatedly, the infrastructural support and cultural changes needed for the successful implementation of initiatives such as "CBI Fusion Point" (CBI-FP) are rarely discussed.

Fusion Point is a collaboration between ESADE Business School, Istituto Europeo di Design (IED)-Barcelona and Universitat Politécnica de Catalunya (UPC) that started in 2014. Bringing together the fields of business and management, technology and engineering, and design, these three schools based in Barcelona gave birth to an experimental context for educational innovation. Together we have delivered seven iterations of the CBI program so far.

In a nutshell, CBI-FP is a 12-credit course that runs from September to mid-December. Approximately 40 students work in small multidisciplinary teams (5-6 people) and meet on a weekly basis in workshops, seminars and coaching sessions. Each team has three coaches, one from each school. The students travel together to CERN three times during the course for a total of 15 days (first two trips are 3 days long and the last one slightly longer; see Figure 1 for an overview). The student profiles are:

- ESADE: full time MBAs;
- UPC: Telecom engineering & computer science (majority 4th year bachelor level from the Telecom School);
- IED-Barcelona: Different design programs (majority 4th year bachelor level)

CBI-FP has been described by our students as a life changing experience. In addition to giving them the opportunity to visit and interact with CERN, which is undoubtedly a major attraction for students in CBI, it also allows them to experience the process of innovation from start to finish, deal with high levels of uncertainty and frustration, learn to interact and work with people with different backgrounds, and engage with actual users and other stakeholders in real-life contexts.

CBI has also been a life-changing experience for the academic team, equally uncertain and frustrating but also enriching. Among the many challenges we have had to face over the years, perhaps the most difficult has been explaining what exactly happens in CBI-like courses and describing the effort they require for making them possible. This article presents the reflections of a multidisciplinary team of teachers and researchers involved in CBI-FP in different roles since 2014[i] and tackles the following questions: What are the key characteristics of CBI-FP that are unique and effective, but also challenging? What infrastructural support and cultural changes do CBI-like programs necessitate?

THEORETICAL BACKGROUND

To better understand our CBI experience, we draw from literatures on design thinking, challenge-driven education, and experiential learning. The links between CBI-FP and design thinking and challenge-driven education are perhaps self-explanatory, as these elements were embedded in the original CBI designed by CERN's IdeaSquare team. Our attention to the experiential learning literature, which is the oldest and most theoretically advanced body of work of the three, came about as we began thinking about some of the challenges we observed in CBI-FP. More specifically, we realized that for CBI-FP was for our students not only an opportunity to learn about innovation, more importantly perhaps, it was an experiential learning journey.

Experiential learning is positioned as a synthesis of the works of various well-known scholars "who gave experience a central role in their theories of human learning and development" (Kolb & Kolb 2017, p.8). These scholars include William James, John Dewey, Kurt Lewin, Jean Piaget, Carl Jung, Mary Parker Follett to name a few. According to one of the latest articles by David Kolb (ibid.), the author of the 1984 ground-breaking and very influential book "Experiential Learning," many of the non-traditional educational innovations of the past few decades, such as competency-based and professional education, are linked to experiential learning. For educators, Kolb & Kolb state (2017, p.7),

> "the magic of experiential learning lies in the unique relationship that is created between the teacher, the learner, and the subject matter under study. The experiential approach places the subject to be learned in the center to be experienced both by the educator and the learner."

Design thinking has been described as an active learning method where students experience different phases of the learning process through feedback and reflection. Design thinking is more dynamic than the typical classroom methodology where the goal is to help students understand predefined material and master certain techniques. By contrast, students learning through design thinking are asked to leave their chairs and classrooms and go out in the real world to observe and take notes (Beckman & Barry 2007; Glen et al. 2014). According to Micheli and colleagues (Micheli et al. 2019), definitions of design thinking link the term to processes and personal characteristics (thinking or sensing) with the aim to create viable business. In general, design thinking is often used in parallel to human-centred design and innovation and is widely regarded as an effective approach to creating new products or solutions that address specific user needs.

Challenge-driven education is considered to be a recent strand that positions students against real-life challenges and ask them to address them by working in teams, drawing on different disciplines and collaborating with organisations and stakeholders beyond the walls of their institution (Mulgan et al. 2016). Challenge-driven learning is regarded as complementary to mastering a specific field of study because it provides an opportunity for students to apply their knowledge in practice. As Mulgan et al (ibid) note, challenge-based learning echoes ancient traditions of learning that start with challenging questions and which can be traced back to Socrates. Arguably, the essence of design thinking is also not new, yet it has cast a new light on the importance of empathizing with the people whose needs or desires your ideas, products and solutions aim to address.

While this literature sheds light on several characteristics and constitutional elements of CBI-FP, it does not consider the challenges of implementing such programs. Our study, therefore, aims to contribute to this body of work, by making explicit the realities of the teaching experience of delivering learning programs that are experiential, challenge-driven and apply innovation processes neatly captured by design thinking.

METHOD AND DATA

Our article draws on qualitative research methodologies grounded in ethnography. There is a long trajectory of ethnographic research in anthropology (Clifford & Marcus 1986; Geertz 1977; Malinowski 1922) and there has been a growing interest and application of its core methods in innovation and product development (Otto & Smith 2013; Suchman 2011). Although definitions of ethnography may vary, there is a broad consensus about its principal characteristics, namely: a) data-generating practice that is built on fieldwork, participant observation and interviews; b) an analytic framework that is aligned with pragmatism and grounded theory; and c) a practice of representation and writing that relies on the writer's descriptions of practices observed, usually presented in a narrative and storytelling manner (Van Maanen 2011; Watson 2011).

The data informing our research was collected over a period of eight years through our complete immersion, active participation, and direct observation of CBI-FP. We adopted an iterative and recursive research process typical in anthropology where data collection and analysis are simultaneous, and research is adjusted according to the information or challenge at hand (Fairfield & Charman 2019; Srivastava & Hopwood 2009). The analysis of our data, therefore, is also spread over the eight years during which we designed and implemented CBI-FP. It primarily took place through a reflexive process designed to generate insights and develop solutions or ways to incorporate the lessons learned from our data into the subsequent editions of CBI.

More specifically, throughout each academic year, the academic team involved in CBI meet on several occasions to share information and discuss observations (see figure 2). The academic team has weekly reunions while the course is running and three annual meetings outside of the course months, resulting in an average 11 meetings each year. Furthermore, this team convenes at the end of each edition to reflect on the main challenges and lessons learned. It also comes together annually to plan the subsequent edition of CBI, putting in place all the new elements for experimentation. All reflections and decisions of the academic team meetings have been documented, and some joint publications presenting our observations and learnings have already been published (Charosky et al., 2018a, 2018b; Hassi et al., 2016). The first author, who is trained in anthropology, has extensive fieldnotes of all our CBI iterations, including records of the numerous conversations and reflections about format, content, methodologies and outcomes.

Additional data informing our article has been generated through the Fusion Point Research Workshop Series, which in the past two years has provided a platform for reflection and tackling of specific topics and challenges endemic to CBI with other internal and external interlocutors. Finally, through Fusion Point's participation in the Erasmus+ Knowledge Alliance project VISION "Envisioning the Future of Teaching and Training for Creativity, Innovation and Entrepreneurship" (vision-project.org), we draw from the 130 interviews with relevant experts around the world whose insights help us to better understand the critical shifts underway in the learning landscape within which CBI is grounded.

RESULTS

CBI-FP has seven characteristics that are important and impactful, but at the same time challenging to organize for. We describe each of them below together with their organizational implications and summarize these in Figure 3.

CBI-FP offers a *challenge-driven* learning context. Students learn by applying knowledge in practice to address real-life challenges that are open-ended and complex, requiring the ability to learn across multiple subject areas. To create such contexts, the educational organization needs to be able to establish a network of experts and key stakeholders of the challenge to define the challenges as well as inform and support the work of the students. This is key in facilitating the work of student teams operating within a strict time frame, as well as supporting the potential continuation and implementation of the project after the course itself. This calls for the role of an ecosystem architect, to build and manage the network of various current and potential future collaborators.

Teams need to form collaborations with third parties in an agile manner, and to have access to off-campus locations for project work. In CBI-FP, learning takes place in a *hybrid-environment*, not established within the boundaries of any single organization or context. Students work in various environments: in flexible working spaces and workshops on different campuses, as well as in real world (off-campus) locations to carry out field research and interact with the target population and stakeholders. This implies moving away from a strict campus-focused model for the learning environment to a model where learning is more closely integrated with existing real societal processes and context.

The scope of learning transcends disciplinary boundaries, as both student and faculty involved represent various disciplinary areas. Due to its *multidisciplinary* nature, course delivery does not depend on a single faculty member, but on a well-coordinated team of faculty. This has at least two direct implications. First, to create such a context, collaboration either across departments of a single organization or with schools representing other disciplines is required. Secondly, to lead a coordinated effort of the multidisciplinary faculty team in the service of designing the overarching learning experience, the role of an academic coordinator is required.

The *process* in CBI-FP is not a linear one. Student teams follow a user-centric design process, that is based on iterative knowledge creation. The outcome is not definable at the outset, but emerges during a journey that is iterative, exploratory and experimental. As a result, the needs of the projects and the students are not fully predictable at the outset. Relately, the required program content and hours for faculty involvement cannot be fully predetermined as faculty must be able to adapt to emerging needs as they arise. This calls for a model for course planning, which accepts some improvisation and flexibility in content and hours while the course is running.

Learning happens through teamwork in heterogenous groups of students, faculty, industry partners, target users etc., forming a large community of co-learners in the process of addressing a challenge. To support this collaborative learning, there is a need to organize and facilitate regular feedback and reflection sessions between the different parties, as well as ad-hoc sessions as the need arises. This poses a significant change to the role of the teacher. Rather than the role of an expert sharing discipline-specific knowledge, faculty members provide the main learning support to the students through *the role of open-minded coaches*, trained in innovation and capable of integratating several areas of knowledge. Due to the exploratory nature of the projects, students' needs for coaching cannot be entirely predicted. This is true both in terms of time required and content expertise needed. Faculty need to prepare to be flexible in terms of availability, as well as to know how to reach beyond their own expertise area to fill necessary knowledge gaps.

The aim of the program is to direct the individual learning effort to create a *positive impact on society* in the form of new or improved products, services, and processes, either as new start-ups or as projects within existing organizations. Learning does not happen solely as an intellectual exercise but has a concrete impact beyond the individual. The educational institutions face the need to encourage and facilitate the jump from academic learning activity to the creation and scaling of new solutions. A structure to bridge the gap between academia and the society is needed: a program and resources to support the maturing of very early-stage projects, with the objective of improving the rate of student-developed solutions reaching the market

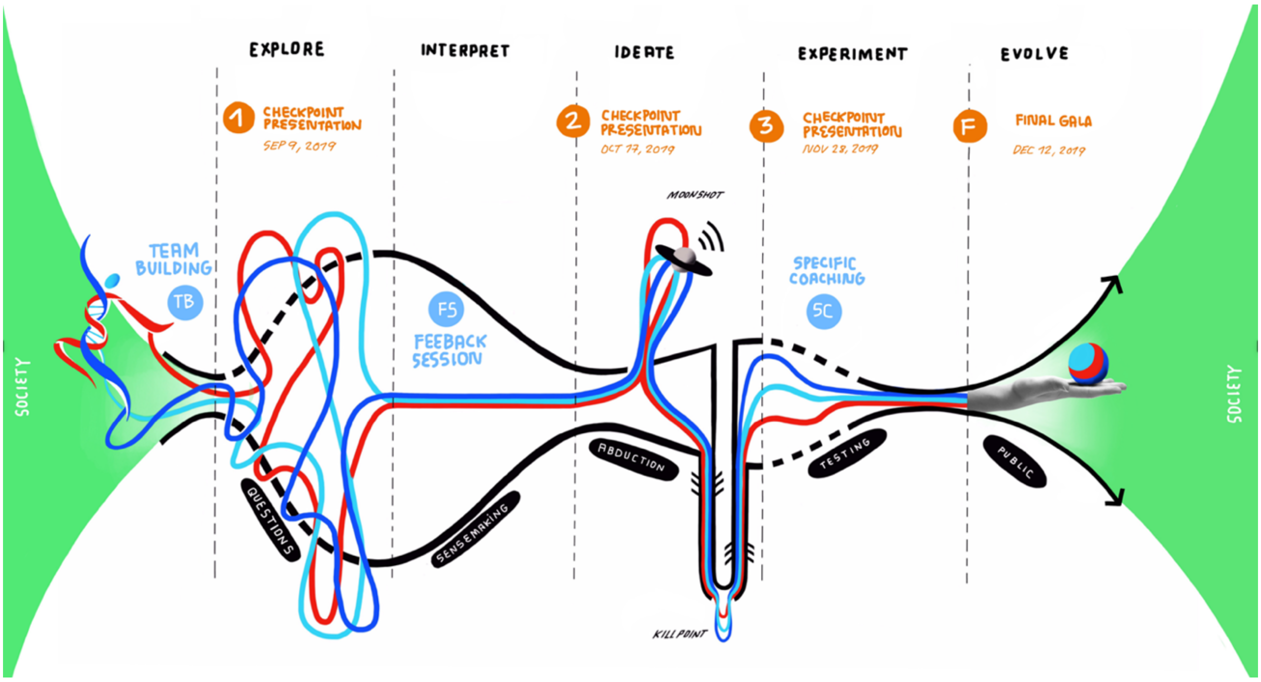

Fig. 1. CBI Fusion Point Journey Itinerary, concrete example from 2019. The blue, light blue and red colours represent the Fusion Point partners' core areas of expertise. The three trips to CERN take place right after the checkpoint presentations.

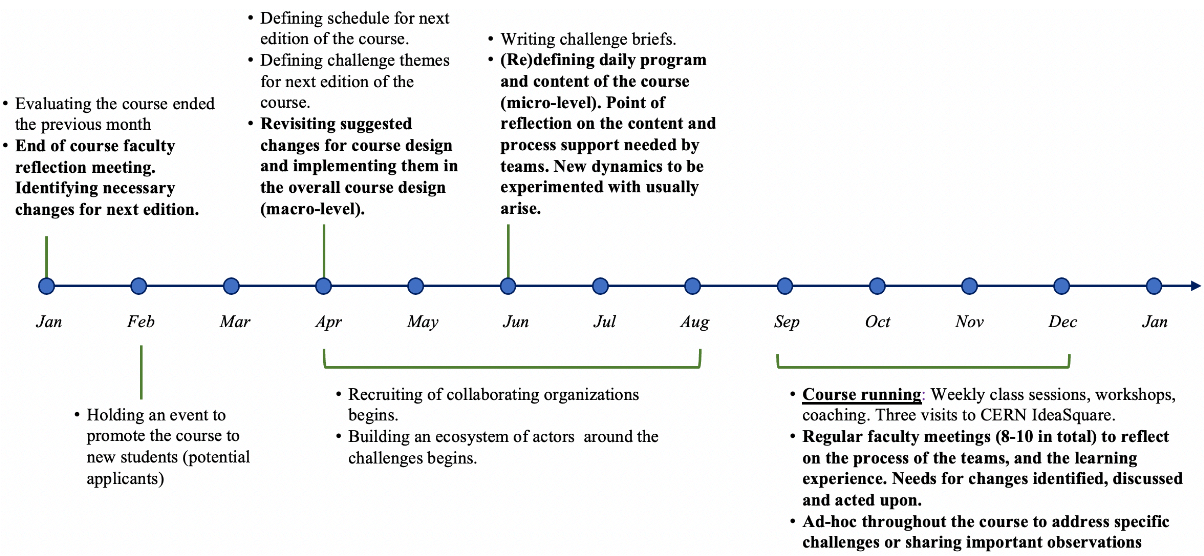

Fig. 2. The annual activity of the CBI-FP faculty team. Data collection points in **bold**.

CHARACTERISTICS OF CBI-FP		ORGANIZATIONAL IMPLICATIONS	CHANGES IMPLIED TO SUCCESSFULLY REALIZE CBI-FP (AND SIMILAR PROGRAMS)
CHALLENGE-DRIVEN LEARNING CONTEXT	Learn by applying knowledge in practice to address real-life challenges that are open-ended and complex, requiring the ability to learn across multiple subject areas	Ability **to establish and manage a network of collaborators** (experts, key stakeholders of a challenge) providing support in the definition of challenges and in the project work on the challenge.	**An "ecosystem architect"** to identify experts and stakeholders in different fields, and to connect the student teams with them in order to facilitate the work on the challenge as well as its future implementation.
HYBRID ENVIRONMENT	Combining flexible working spaces and workshops on different campuses, with third party locations.	Moving **away from a strict campus-focused model** for learning environment.	Need to form collaborations in an agile manner with third parties to create **off-campus locations** for project work. Need for spaces adequate for **flexible (space- and time-wise) project work.**
MULTIDISCIPLINARY SCOPE	Transdisciplinary education, with little (or none) discipline specific technical training. Students and faculty represent various disciplinary areas.	Course delivery no longer depends on a single faculty member, but rather **a well-coordinated team of faculty.**	**Forming multidisciplinary collaboration**. Creation of an **academic coordinator** to lead the design of the multidisciplinary learning experience. **Faculty upskilling:** knowledge on learning processes from other disciplines.
EXPLORATORY PROCESS	The needs of the projects and the students are not fully predictable at the outset of the program, due to the open-endedness of the projects.	Required program **content and hours** for faculty involvement **cannot be fully defined at the outset.**	**A model for course planning**, which accepts some improvisation and flexibility in content and hours dedication to be able to adapt to the emerging needs as they surface.
LEARNING AS TEAMWORK	Learning happens through collaborative project-work with other students, faculty, industry partners, target users, etc.	Learning to be considered as a collaborative effort with a larger community of students, coaches, industry partners, target users, etc. as partners in learning, **co-learners.**	Develop the ability to **organize and facilitate regular feedback and reflection sessions** between different parties and be prepared to arrange ad-hoc sessions as need arises.
TEACHER AS A COACH	Open-minded coaches, trained in innovation, capable to integrate several areas of knowledge guiding students through an open-ended and uncertain process.	Need for faculty that has such **integrative profile and the required soft and hard skills** for effective coaching, and who are capable to manage uncertainty in terms of time and expertise dedication.	A model for the **planning of faculty's time dedication,** allowing flexibility for realized hours, and which **values coaching as equal to traditional teaching. Faculty upskilling:** training for faculty to take the role of a coach.
IMPACT ON SOCIETY	Learning happens through collaborative project-work with other students, faculty, industry partners, target users, etc.	Need to encourage and facilitate the **jump from academic learning activity to the creation and scaling of new solutions**	Bridging the gap between academia and society: **a program to support the maturing of the very early-stage projects**, with the objective of improving the rate of student-developed solutions reaching implementation.

Fig. 3. Main characteristics of CBI-FP, their organizational implications and changes they require for their successful implementation.

DISCUSSION AND CONCLUSION

Our observations and reflections from the seven iterations of CBI-FP point to a set of characteristics that pose unique challenges to the established infrastructures in higher education that have been built around lecture-based and subject-specific learning. For the successful implementation of programs like CBI, which are experiential and challenge-driven, we suggest several broader organizational changes need to take place, such as the creation of new academic and administrative positions (such as an "ecosystem architect" or an "academic coordinator"). These changes, we also argue, have important implications at the policy level, as they are particularly pertinent for all organizations that aim at enhancing their students' and employees' creativity, innovation, and entrepreneurship (Papageorgiou & Kokshagina nd; see EU & OECD HEInnovate initiative https://heinnovate.eu/en).

Here we would like to highlight four shifts in the learning landscape, the effects of which are critical for the successful realization of CBI-like initiatives:

- From disciplinary-centred knowledge transmission to problem-based learning and challenge-driven innovation;
- From learning alone to learning collaboratively
- From traditional classrooms and lecture halls to flexible spaces and the real world;
- From lecturers to coaches, facilitators, experiential learning designers and beyond.

The latter shift is important to emphasize because it presses against one of the core pillars of modern higher education – the lecture-based tenure faculty model. CBI has enlisted educators for various backgrounds and positions who have had to switch from standing in front a classroom and delivering lectures to taking an active role in the students' learning jouneys as mentors and coaches, providing different types of support and guidance depending on the different phases of the course. Beyond the changing roles of faculty, CBI has demanded that we also become learners and practitioners of educational innovation. Further research is needed to better understand the novel faculty and administrative roles, course formats and methodologies for experiential learning that effectively respond to broader shifts in higher education. As we continue moving forward using the "license to dream" that we received from CERN, we realize more than ever that the success of CBI-like projects is dependent on dedicated support, strategic investment in new learning infrastructures and cultural change.

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Authors would like to thank everyone that has made CBI Fusion Point possible, especially the CERN IdeaSquare team for their continuous support and collaboration. Figure 1 was prepared by Irma Arribas. Part of the research informing this article has been supported by the EU Erasmus+ Knowledge Alliance

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[i] The fourth and fifth authors were first involved in CBI-FP representing IED Barcelona.

Annex C – Certificates

Certificate of participation in the 4th International Conference on Higher Education Advances (HEAd'18), Valencia, España, 20-22nd June 2018

HEAd'18

Certificate of Participation

Guido Charosky, Lotta Hassi, Luciana Leveratto, Kyriaki Papageorgiou, Juan Ramos, **Ramon Bragos** contributed to the *4th International Conference on Higher Education Advances* held at the Universitat Politècnica de València (Spain) from 20th to 22nd June 2018, with the following paper presentation:

Education for innovation: engineering, management and design multidisciplinary teams of students tackling complex societal problems through Design Thinking

Josep Domènech
General Chair, HEAd'18

Certificate of participation in the SEFI Doctoral Symposium, September 2018

CERTIFICATE OF ATTENDANCE

Awarded to

Guido Charosky, UPC Technical University of Catalonia

for participating in the 2nd **Doctoral Symposium in Engineering Education** on Monday September 17, 2018. The Doctoral Symposium took place in connection with the 46th SEFI Annual Conference arranged by Danish Technical University, Copenhagen. The symposium was organised and chaired by Jonte Bernhard, Linköping University, Kristina Edström, KTH – Royal Institute of Technology, and Tinne de Laet, KU Leuven.

The aim of the Doctoral Symposium was to provide an opportunity for doctoral students and supervisors, to

- meet other students and supervisors to extend their network and view of the Engineering Education Research (EER) field,
- present and discuss their own work and the work of others,
- get perspectives from scholars outside their own institution,
- contribute to the conference and the SEFI EER community with other participants,
- and promote collaborative research and elaborate future research directions.

On behalf of the Organising Committee

Jonte Bernhard
Professor in Engineering Education
Linköping University
jonte.bernhard@liu.se

Annex D – Coded documents PDP and CBI

1 # CBI_15_0

2 We wanted to thank you for the opportunity to participate in the CBI as well as for all the efforts and dedication that you have put to ensure that the program could work.

..Uncertainty management

3 These days we have been discussing, and although sometimes have been difficult, we are all very pleased to have participated in the CBI and we would enroll again if we would again start it. Having being working at CERN, in collaboration with many universities and institutions has been a privilege and a great way to finish the degree.

..Self-awareness for prc
..Communication
..User awareness
..Multidisciplinarity
..Coordination
..Critical thinking
..Business sense

4 In addition to having made a technological project and having worked with things that are not taught in the degree, we have learnt a lot from other branches which are in principle not taught in engineering and that surely they are essential in the professional world: to clearly present ideas, to study and respond to the user needs and to work in teams with diverse composition, solving conflicts to reach a coherent and unique solution. In this regard, we believe that the CBI has done exactly the function that a PAE* should do: to offer a comprehensive vision on how to develop a project and provide the tools to turn the work into a technological product with demand and that can last.

..Self-efficacy

5 That's why we wanted to thank you for having had the initiative to start this project, we believe that the learning outcomes have brought us great value as engineers and we are very grateful for the effort and dedication involved.

1 # CBI_15_1

2 After taking part in this CBI experience, I would like to give my personal impression about both the points I have enjoyed and those I consider could be improved in future editions:

3 **1. Student selection and team composition**

4 I think that student selection has been unfair. Comparing with students from the different universities, some of us have followed an application process, including motivation letter, grade ranking, etc., but others haven't. In addition, I do personally consider that some students have been accepted for the sake of parity among countries, not based on personal merit, and this has closed to the door to other students who were better prepared.

5 In addition, at least for UPC case, I think this subject is not well publicized – actually it was a matter of chance I heard about it, because it was not offered in the Master's "official" curricula.

6 Regarding team composition, I think it has been quite equitable. For the particular case of my team, I would have appreciated more MBA and engineering students.

7 **1. The figure of a coach**

8 From my personal point of view, our coach has not supported us as much as she could have done. I have the impression her contributions have arrived late, mainly oriented towards Italian section of the team and "in parallel" to team's project development, instead of getting involved in the progress.

9 **1. Teaching team**

10 I am really happy with teaching team, all of the professors have showed a great implication on the course and they have supported us as far as they could, until the very end of the course. In addition, I really appreciate logistic support, especially that which we students received at CERN.

11 Furthermore, I would like to thank the extraordinary effort for giving visibility to the projects and organising diffusion of the final presentation.

12 **1. Course structure and contents**

..Multidisciplinarity

13 This course has been really different from any other I have taken in my university. On the one hand, I consider it a great experience, because I have learned a lot about other disciplines and I have experienced what it means to work hand in hand with them.

..Uncertainty management

..Organization

14 On the other hand, I have the impression we were never told in clear terms what the course was about or what we were expected to do. Besides, role of each of the involved disciplines was never stated, so again from a personal perspective, I think this leaded to an unbalanced distribution of tasks, in which engineers ended up with more work than others.

..Multidisciplinarity

..Communication

15 Regarding course content, I do really appreciate we had sessions on financing, design thinking and lots of presentations, which was very helpful to improve communication skills. However, I think it could have been interesting taking some sessions on more technical aspects as well – especially those which most of the groups required, such as big data, databases, etc.

..Uncertainty management

..Critical thinking

16 In my opinion, engineering side has been really disregarded for the whole course – I would be fine with that if so was stated from the beginning, so that students who would apply for this subject could know what they would actually find, but this has not been the case.

..Time management

17 About working at CERN, I do understand pressure and time constraints are part of the experience. However, and taking into account that most of us were taking more courses beyond CBI or were involved in other projects, and taking into account that all of the teams had to rush in the end, I think it could be helpful to revisit course schedule so that the last week at CERN could be less stressful. I think this would be beneficial in terms of productivity, team dynamics and personal health.

..Time management

18 What I did particularly miss in the last week at CERN was a more precise schedule of rehearsals, presentations, etc. – at least, a more rigorous accomplishment of provided schedule.

19 **1. Workspace**

20 Regarding ESADE Egarage, I think it was fine for prototyping, but not

suitable for lectures or Skyping with the Italian counterpart, there was not really a quiet space. About Espai emprèn at UPC, it was more comfortable for working, though we would have appreciated more plugs.

21 Finally, regarding IdeaSquare, it was absolutely impossible to work there. Offices were really noisy and, in some cases, they were office and corridor simultaneously, so there was a continuous flow of people crossing the office because it was the only available path. Besides, receiving visits of investors, etc. constantly really disrupted work dynamics.

22 **1. Role of CERN**

NETWORKING

23 Unfortunately, for the case of my team, CERN did not play any significant role. We could have obtained all of the collected information from other sources.

..Critical thinking
NETWORKING

24 In addition, I must say that I am personally disappointed with course organization in the following aspect: as I was taking part in a subject with the explicit opportunity of going to CERN, I strongly expected we could visit some experiments and get to know its research activities. However, we have seen almost nothing of that.

25 I do really appreciate the visit to ATLAS control centre with Markus, but we have seen nothing of other centres or experiments to which we could have accessed – testing facilities, conferences, etc. I am aware that we could have organised it ourselves, the problem is that there was no time reserved for that, which I know is mainly interesting for engineers, while we did actually have sessions on economy and art activities.

26 **1. Multinational dynamics**

..Communication
..Multidisciplinarity

27 Working with Italy has been really nice in the personal aspect and very interesting in cultural terms. In addition, working via Skype was helpful and by far less dramatic than expected.

..Coordination
..Time management

28 However, we had difficulties when coordinating because there was no time devoted for working together within course schedule, save for days at CERN. We had lectures on different days, so teamwork was not facilitated.

29 Finally, I must complain about one member of my team in particular: Fabrizio Zucchini. He had a very collaborative attitude, but eventually he did not contribute at all to the teamwork. In my opinion, this is not a matter of his personal disposition, but some sort of limitation of skills.

30 **1. Further support**

31 I consider budget for prototyping is excessive for the type of prototypes we were asked to develop. As an alternative, I think it could be more profitable devoting part of that budget to fund student expenses associated to trips to CERN.

32 In conclusion, this has been a very good personal experience, but it has not fulfilled my academic expectations. I hope this feedback has been helpful and I am open to discuss any of the points presented.

33 Happy New Year and best wishes for further editions

1 # CBI_15_2

2 Challenge Based Innovation 2015 has arrived to its end. It is a shame because we were feeling very privileged working there, we had already created a family and we had made from IdeaSquare our home. We will miss the kitchen, the bus, the cold wind while riding the bicycles in the morning, the “Florette” salad from the gas station... But we are also very happy because we have learned a lot during this 4 months and this experience has definitely made an impact in our lives.

3 I remember when I was writing the letter of application for the CBI, I had heard something about CERN but I didn't know what exactly it was. But the professor that came to our class to talk about this innovative program mentioned about learning different ways of creating solutions, collaboration in multidisciplinary teams, going abroad in a top scientific community... I had no idea of how CBI could be, but something inside me was telling me that it would be great.

..Energy
..Uncertainty management

4 And then one day we appeared in ESADE E-Garage with some friends, and a lot of new people to meet. And the teachers started talking about something completely new and different for me, design thinking... And I couldn’t imagine that something so big would be arising from there.

..Social impact
..Energy
..Leadership/Initiative
..Organization
..Uncertainty management
..Self-efficacy
..Idea generation

5 There has been 4 months of working really hard. Some really good moments, some more difficult ones. I have been dressed with a leadership role in the team, taking decisions and trying to make the project advance properly. But this is not always easy when you are working with people with so different backgrounds, with so different ways of thinking and, at some moments, you don’t feel that the project is following the right path. I think that my piece has been key in the team. Adding a realistic drop in the project when needed, when ideas were going to out of the box, or when team members seemed to be worried, too enthusiastic or even sleeping.

..Leadership/Initiative
..Self-efficacy
..Communication
..Energy

6 And here I would love to remark that I have been very comfortable in this role, specially having the confidence of my other partner with technological background, Sergi, with whom the relation has been extraordinary, always thinking the same, he technically stronger than me but I having more power in communication. We have been a perfect puzzle. Same methodology, same passion for perfection. I still remember that weekend, last Saturday and Sunday of the project, everyone in Geneva having fun, and we in IdeaSquare soldering until 3 midnight... without him it wouldn’t have been possible.

..Leadership/Initiative

7 In the feedback last session my team members thanked me for having been key in the project with my attitude, common sense, hard work and

..Leadership/Initiative

..Self-efficacy

humour, which is also really important when working. And I wouldn't have been able to provide all that drops to our project without being comfortable with the team. I have always felt very relevant in the team, I have always noticed a lot of support and confidence on me and that has been fundamental during the development of the whole project.

..Coordination

8 Without the cohesion of the team we wouldn't have been able to develop such a good idea. Even though we have had some disagreements and discussions in some points, the respect and the empathy have been our value and, with them, we have been able to skip all the stones on the road.

..Entrepeneurship

..Social impact

9 I personally think that the project has a lot of future. Having won the Challenge Based Innovation 2015 makes you have a bigger impact in people's impression, and the feedback that we received the day of the exhibition couldn't have been better.

..Self-efficacy

..Social impact

..User awareness

10 Comments like: "I really love your idea because you haven't invented the wheel, but you have made it spin" or offers like linking our project to Gates Foundation, give you a lot of confidence in relying that the project is in the good direction. But if I had to choose one feedback I would say without hesitating the moment when I had to explain the project to the only attendee from Mali, Africa of the whole event. We had been trying to develop the most accurate and precise solution for a country that we didn't know, that we hadn't been in, and our objective was to create a solution absolutely adapted for them, thought for them, and to be used by them, and, watching that local people, who know better than no one the problem, really appreciate your solution and find it fabulous is the best feedback I could ever expect.

NETWORKING

NETWORKING

11 The fact of working with such a good institution as CERN has made us build a very powerful contact network. Thanks to c2mon technologies we will probably be showcasing our project in CeBIT 2016 in Hannover this spring.

..Entrepeneurship

12 Concerning my future role in the project, I have been developing the idea from the beginning to the end and I have never wanted to quit. I don't know if we will be able to implement it ourselves or not. I have a very scheduled agenda, and during this year I will be in GaTech continuing my studies so I don't know how this will affect my relation to the project, but at least, my idea is to give it a chance, to try to bring it a step further and then the future will say.

..Idea generation

..Entrepeneurship

13 This project has helped us to develop other very interesting ideas as well. Eva Vidal proposed us to go further with the idea of the platform that aimed to empower local people to explain their day to day situations and to let them contact people of developed countries,

..Entrepeneurship

NGO’s, and create a hole ecosystem. I also think that that was a very powerful idea, not as a solution for our CBI as we all agreed, but interesting to carry on. Eva asked us to do it, but we still don’t know if we will have time for everything.

..Self-efficacy
..Idea generation

14 At the end what we get from all that, is that if you propose something to yourself, you are capable of developing amazing solutions and coming up with great ideas. The only thing we need is time to make them all come true.

NETWORKING

15 In reference to if we hope to receive any help from the institutions / professionals, I don’t know if we will need anything or not but having their contact and knowing them personally we can feel safe that we could have their support in case we needed it. As well, if there was anything we could help them with, we would be more than pleased to do as much as we could.

..Social impact
..Self-efficacy
..Uncertainty management
..Self-efficacy
..Leadership/Initiative
..Self-efficacy
..Self-efficacy
..Energy

16 As I said before, at first I couldn’t imagine that our project would create such an impact. I have always been very self-confident and I always love to think that if I propose myself something I will be able to do it. It is true that in some parts of the project I didn’t like the path that the team was deciding it to follow, giving importance to determinate ideas, working in determinate ways... but at the end we have been able to choose a solution which I have been very comfortable with and the results have been absolutely great. I have always pushed the project in the direction that I hoped. As I said before I was a little bit the voice of the technical view in negotiations inside the team and all the members have always taken very much into account my points of view and everything I hoped has finally come true. And I think that we have done an amazing job. I am very happy with the work developed, it has been a lot of hard work, but at the end the efforts have been paid off.

1 **CBI_15_3**

..Multidisciplinarity
..Multidisciplinarity
..Coordination

2 As the teams were multidisciplinary, this project was a big change from all the other projects I have been doing since I started University. I think that the fact of working with people from other disciplines gave me an insight of the real world that I couldn't have received from any other place. So I find that being able to do this project was really valuable.

..Entrepeneurship
..Multidisciplinarity

3 About the fact of the multidisciplinary teams I have to add that, before doing this project I thought that other disciplines were not as useful as my own. Now I can see that the part of engineering needs all the other disciplines as much as they need us in the process of building a company.

..Self-efficacy
..Self-efficacy
..Risk-propensity
..Self-efficacy
..Communication
..Leadership/Initiative
..Self-efficacy
..Idea generation

4 From the perspective of what I have contributed to the project I have to say that I am proud of what I have been able to achieve. At the beginning of the course (and also at the end), I felt like if I was continuously going out of the comfort zone. I had to face several problems that I wasn't used to, so I had to learn a lot, and also quickly. In this project I realized that I am good at talking to people and understanding other points of view, I managed to lead the team towards consensus in several situations, and I could see that this is something that not everybody can do. Another thing that I would like to highlight is that I had an important role in the idea generation, from my point of view the challenge of my group was quite difficult, so I am really proud that I have been able to contribute that much.

..Energy
..Problem solving
..Time management
..Self-efficacy
NETWORKING
..Entrepeneurship

5 The first thing that I would like to say about the future of the project is that there is still a lot of work to do. There are several aspects of the idea that we should find out if they are really feasible, in my opinion, there wasn't enough time in the course to find out if it is one hundred percent implementable. From my point of view, the concept of the idea has got a lot of potential, and we had support from iConsulting and other entities, which is a good sign. Once we continue the research and try a prototype with the costumer we already have, the idea would be to create a startup. The role that I would like to play if we create a startup is

..Entrepeneurship
..Leadership/Initiative
..Uncertainty management
..Time management

6 not only in the technology part, I would like to take part in all the decisions made within the process and also when the company grows. One problem that I can see is that I haven't got the experience necessary to create a startup at this moment, I think that nobody would trust a boy that haven't even finished the degree, so the part of getting funding would be really difficult. Another problem is time; if we want to

..Time management

carry forward this project it will take time away that I haven't got, for the moment, the priority is finishing my studies.

1 **CBI_15_4**

..Energy

2 I've loved to work on this project. As a whole experience overview, I've learnt a wide number of different things. The most basic one is English. As CBI is meant to be in English and as it's members (both students and teachers) are from different countries speaking different languages, that has allowed me to have an immersive experience where I've been able to improve my English skills. But I've learnt more than English. Working in a multidisciplinary team has taught me how to deal with situations where really different people in terms of problem solving approach have to work together to solve that problem. Being able to listen to business and design people when they explain their own part-solution has taught me a lot of methodologies and concepts from those areas, which I have backed up with the lessons that we were provided through out the program. I think that this lessons were great but some times out of schedule in the sense that maybe we needed some of them earlier in the process. The teaching team feedback has been really good and I've really appreciate the help that you provide to us, which has allowed us to end with this solution.

..Multidisciplinarity
..Problem solving
..Multidisciplinarity
..Self-efficacy
..Problem solving

3 In terms of my role, I liked very much for different reasons. In the technical aspect I have learnt a lot of computer vision and C++ programming (which is going to be really useful for my TFG). But as I've also love design (specially graphic design) I think I was able to provide good feedback in terms of interface design. I always like to know what is happening in all the stages of a project and that's why I talked and discuss with Nick about business and with Javi and Christoph about the design, which allowed me to also work (briefly) in other things different than coding. The only downside of my role is that I was hoping to work on hardware, as I also love it and I wanted to put in practice some circuit design or learn about Arduino/Raspberry Pi. The problem is that I am always the software guy as I have a lot of experience in that area and that allows us as a team to make this part faster and do more advanced stuff. But as I mentioned, I really loved to work on this software despite the fact that I wanted to work on hardware.

..Technical solution/Technology
..Multidisciplinarity
..Multidisciplinarity
..Experimentation

..Coordination

4 One of the best things of this project was my team, because I've really get along with them and they all are great both in the “knowledge” part and in the personal aspect.

..Uncertainty management
..Business sense
..Business sense

5 I am not sure about the future of this project. As it's a more NGO style project, the economical part is tough even if we have designed a sustainable business model. The process of really making this project work is hard as it involves a lot of different parts such as production, shipping and most important work in

..Business sense
..Entrepeneurship
..Social impact

the ground. These are my concerns about the project but in the other hand I would love to make this work. For me, even if it's one of the main “problems”, being a social project that aims to help people with huge needs is the best part of it. I love that this could have a great impact on society and that it could help a lot of people.

..User awareness

6 Taking into account the feedback we received from local people from Ghana, I am convinced that this is a really good idea.

7 Issey Masuda Mora 2/1/2016

..Experimentation
..Energy
..Entrepeneurship
..Business sense

8 My overall opinion right now is that I want to make at least a first fully functional prototype and deliver it to one of the villages in Ghana in order to test it and to turn this “university project” into something real. I think that making one Bam-Boo could be feasible in terms of costs and then, after we would have the results, we could decide if we move forward or not.

..Uncertainty management

9 Of course, I would love to do that with my team, but this is a personal decision. At the end, it's not clear which is going to be the future of Bam-Boo.

10 One thing I am quite sure is that I'll probably going to work in some other projects with them, as I found really good (professionally and personally) people in this team.

NETWORKING

11 Summarizing the whole process and experience, it has overpassed my initial expectation (in the good way!) even if they were quite different from what it really was. I recognized being a little bit disappointed the day we knew what the challenges were because I had the idea that, as it was related with CERN, the challenge was going to be more directly related with technology. But this disappointment disappeared really fast once I realised the opportunity that the actual challenges were providing us and, at the end, tech was everywhere too!

..Self-efficacy

12 I think that both team and individual results are great and we achieve the best for the time we got.

13 Finally, I just want to say that I am really grateful for this opportunity that you gave to me and I have really really loved it.

14 Thanks!

1 # CBI_15_5

2 ## Personal reflection

3 CBI has been an enriching experience from all the perspectives. I have enjoyed not only the project but also the teamwork and the environment of CBI. Although the course has broken all my initial expectations, this project has taught me a lot of key skills that are crucial for the professional life.

4 The experience has given the opportunity to have a first approach to the professional world where multi-disciplinary teams are the most common reality. Working in a multi-disciplinary team has been the most fruitful and hardest part of the course. All the disciplines have their own structures, procedures and workingcultures that caused discussions and disagreements that in long-term produced positive outcomes. The designers have taught me to keep my mind more opened to crazy ideas that, after a while, could evolve to very good ones. On the other hand, from the MBAs I have learnt project management skills such as autosuggestion, self-projection, leadership and conflict management.

5 My main role in the team has been the organization and management. Adapting the work patterns and aptitudes of each member to the team necessities has been an indispensable fact to achieve high quality results. I usually coordinated the teammates to meet the deadlines and schedules trying to bring out the best in each team member. In this sense, the project has forced to work in parallel, but always being aware of what the others worked with in order to achieve a common goal. In addition, bringing objectivity to the process has also been important.

6 Concerning the methodology, it has been very interesting to observe the contrast between the different disciplines and how each student contributed with his knowledge. The three constituent parts of the project (business, design and engineering) have allowed to examine the different dimensions that any project should include. It was the first time I was exposed to apply all my knowledge to my own ideas without following pre-set steps and I have learnt a lot about it.

7 Furthermore, the fact that the aim of the project was to provide a solution to reduce youth illiteracy in developing countries was a great incentive. We had the opportunity to verify that our knowledge and our ideas can have a positive impact in the world. The education challenge raised my motivation to contribute with new ideas and solutions as their impact might

..Idea generation
..Energy
..Leadership/Initiative

improve the quality of life of a lot of people. Although I have loved working in the education challenge, I do not think we are going to proceed with our project. However, the project has aroused my interest in taking part in cooperation programs in the future.

..Multidisciplinarity

8 Another aspects that have contributed to the experience are the classes. Particularly, I really enjoyed the business classes taught by some professors from ESADE and the patents class. Nevertheless, I would like to have visited more expositions, conferences or activities in CERN.

..Uncertainty management
NETWORKING
NETWORKING

9 The expectations I had before I started the course were very different. I expected a more technical project with stronger connection with CERN technologies. In my opinion, with more time to implement our prototypes we could have received more technical support from CERN researchers.

..Self-awareness for professio
..Self-awareness for professio

10 To conclude, I will define this project as a complete once-in-a-lifetime and valuable experience. This period has also been an opportunity to know myself on a deeper level and further develop relationship and professional skills. I fully recommend the experience.

1 # CBI_15_6

..Uncertainty management ..Technical solution/Technc ..Self-efficacy ..Idea generation ..Critical thinking ..Critical thinking

2 The CBI project has been a great experience for me. At the beginning, I was not sure about my role in the whole project because I thought I would only be useful at the final part when the solution had to be implemented. However, I tried to do my best to also contribute in the other phases. As I am not an extremely creative person, I was not the one who had most of the ideas, for example, in the ideation process. Instead, I had a role of not losing the reality of what is feasible and what is not, being a little bit critical with the ideas that the other team members had. Sometimes, this role may be a little bit annoying for the rest of the group members, but from my point of view, it is totally necessary if the final output has to be implemented.

..Multidisciplinarity ..Multidisciplinarity ..Multidisciplinarity ..Multidisciplinarity ..Business sense ..Idea generation

3 In the context of teamwork, for me it has been amazing to learn the different points of views for a single problem that everyone had. The balance of having two members from each discipline, it was perfect because in the discussions everyone had always someone to rely on and that could help him explaining his point of view. Without this, probably, such good results would not have been achieved because there would not have been such a good equilibrium in the three different fields. From the different outcomes of these discussions, I would like to highlight two. First, I have improved my knowledge about all the topics related with management and economics of a company. Second, I now value much more the work done by designers because they have an extreme creativity which is something that it is almost impossible to learn.

..Coordination

4 I would also like to highlight one fact that I have learnt during the course, especially in the final report part, as a result of working in a team. I am very perfectionist and I always want everything correct up to the smallest detail. Sometimes, the work produced by other team members may not have the quality that I would like, but I have learnt to accept it. First of all, because if I have to redo the work done by others, one of the main objectives of teamwork is lost. Secondly, because some people may feel that you don't value them if you do again what they have done.

..Self-efficacy NETWORKING ..Uncertainty management ..Business sense

5 All the different feedback received so far has been great so we are still considering whether to push the project forward or not. From the C2MON team at CERN, we receive an invitation to participate in a contest organized by Software AG to showcase our project at the CeBIT 2016. We have spoken with them and they have told us that they love the idea and that after the holidays we will talk further to discuss what will be in the showcase of the exhibition. They have not confirmed us yet the participation, but they have shown great interest for the project so probably, we are one of the final candidates that they are considering. In my opinion, if we have this huge opportunity of going to the fair, we could receive more feedback and perhaps

..Uncertainty management
..Business sense

funding to pursue further the idea. If not, it is going to be difficult to continue working on the project because, personally, I have serious doubts about the financial viability of it.

..Entrepeneurship

6 Furthermore, whether it is in this project or in another one, the CBI has opened for me the doors to the entrepreneurship world. In this direction, I found very interesting the lectures that were given related to this topic, for example, the ones given by Carles Puente, Jan Brinckmann and Luisa Alemany. Before the CBI, I had no idea of how I could begin a startup and now I have at least an idea of which are the initial steps and which are the different ways to get funding.

..Entrepeneurship

..Uncertainty management
..Uncertainty management
..Self-efficacy

7 As a summary, I am usually skeptical about new learning methodologies, so at the beginning of the course, I tried to be open minded. As the course was going forward, I started to like more and more this methodology although some phases were pushing me outside of my comfort zone. If in the future I have to do a similar project, I will try to use this methodology.

1 # CBI_15_7

..Organization
..Coordination
..Critical thinking

2 The teamwork has been extremely difficult in our project. We have had a team with very strong members, always working in their own. No coordination has been reached at all, and the final performance has been much better than I personally expected when I was working on the project. There have been unilateral decisions whenever a member on the team wanted, no consulting to the other team members, poor quality work and work done without any research.

..Organization

3 In particular, the work done remotely has been purely independent. There has been some work during the week done by the two parts of the team (Spain and Italy), but no coordination has been reached. I think that the purposes of the two remote teams is differently oriented. We always in Spain have had a lecture related to the course, most of them very interesting, and I personally encourage the teachers to carry on with them. However, in Italy they have not had courses at all, so some of the contents we learnt on those lectures was unknown to them, and we had to pass them the slides, materials, etc. I think that more coordination between the faculty about the purposes of the course is compulsory between Italy and Spain.

..Uncertainty management
..Idea generation
..Energy

4 Personally, I have felt alone many times during these 3 months. I have been sometimes the only one working during the week, from Thursday to Thursday, and doing work that I was not supposed to do (more related specifically to the ideation part).

..Coordination

5 For example, I have arrived Thursdays at 8 AM, one hour before the lectures, having my work done, more related to the research on the technical part or prototype testing, but having to present some deliverables. These deliverables were totally empty, so I had to hurry up during 1 hour to fill the deliverable as fast as possible, with the consequence of delivering eventually a poor and fast work done by the least specialist person in that field. But the worst thing here was that we had agreed that some other people would do that during the week. I specially highlight this because it happened twice.

..Coordination
..Multidisciplinarity

6 Working with our designer has been the worst and most difficult experience I have ever had during my courses. Maybe I am very far from their point of view, but I have seen on other groups amazing work done by the designers. The designer has not provided any added value to the team, and have always argued about all the decisions that all the other 7 of us agreed on. Her answer was always that we were not considering her because he was a girl or because she was a designer, but this is completely false. She has often not done the work assigned to her, and even IED professors have also got mad with her. I am not blaming her about everything,

..Coordination
..Multidisciplinarity

but I personally consider that she has difficult notably all the other 7's work, and the quality of the final result may have been affected because of that.

..Business sense
..Technical solution/Technc
..Technical solution/Technc

7 However, I am very proud about the work done in both technical and economic parts. Talking about the technical, we have finally managed to create a box with a novel material combined with another insulating material (vacuum) with amazing insulating properties. Moreover, we have proposed a novel architecture for the sensing part, working with nodes without battery in order to save the final amount of money of the system.

..Self-awareness for professional

8 All these negative parts have finally had a positive effect to me. I have learnt many things here that any theoretical course or lecture can teach, and I feel much more prepared now for the real life, real projects and real work. CBI has been the most exciting experience I have had during my university life, and I am really looking forward to another experience like this in the future.

..Self-awareness for professional

9 I have learnt a lot here, not only on the technical part but also on some other disciplines, very important for the working life of an engineer. Moreover, on the social part, I have learnt many very valuable things that I will always apply.

10 I would really like to thank the faculty and all the people involved here to make this incredible experience possible.

NETWORKING

11 Regarding the future of the project, I know that some of my mates will join Prometheus Accelerating Program, from Reimagine Food. I think that this is a huge opportunity for a solution with high potential, and I wish the best for them. I have not carried on with the project mainly because of a reason: I think that this project requires a 100% dedication on-site, and in April I am going to MIT (USA) in order to pursue my Master Thesis there, so it is not possible for me to continue. I also think it is not fair for my teammates for me to continue with the project, since I would not be able to give the dedication that this project requires.

..Self-efficacy
..Self-efficacy
..Coordination
..Self-efficacy
..Self-efficacy

12 And last but not least, I think that for the other members of the team I have been a valuable member. I have contributed to the technical part, and to the other parts as much as I have been able to, and I have helped the other members whenever they needed help. I have become a strong member when the technical part have finally arrived, and I have felt very comfortable working there. I feel very proud of the final outcome of our project and I would like to encourage everyone to join this amazing program in future editions.

1 **CBI_15_8**

..Self-efficacy
..Leadership/Initiative
..Self-efficacy
..Multidisciplinarity

2 Personally, I believe that my contribution to the group has been wide and I feel I participated in every decision. I believe that I have not limited my role to only my field but that I have contributed in the direction of working and that the other team members have been enriched with my knowledge and ideas. It is true that the distance learning has been chaotic but whenever we had the opportunity to work together I believe I done my best.

..Coordination
..Critical thinking
..Organization
..Uncertainty managem
..Organization

3 However, I believe that may problems have arisen when we had to work in distance. We have been poorly organized and we felt we should have had some coaching to help us with the general organization. I deeply believe that the strategy of having a working counterpart has been one of the worst ideas for organizing the distance working. I my opinion one person of each part should represent their local mates and talk with the person on the other side. In my opinion working in distance is hard and adds an unnecessary complexity to the challenge.

..Communication
..Coordination
..Organization

4 I also believe that we were too many people working, 8 people in a single project plus the working distance made the organization and communication almost impossible. I believe that with few people we could have been able to communicate better.

..Idea generation
..Entrepeneurship
..Self-awareness for profes

5 On the other hand, the learning experience for me has been great, I believe I have participated in the process of giving birth to an entrepreneurial idea. I feel more prepared than before. What I did not like from the project was that we were very restricted in comparison to the freedom that other teams had.

..Social impact
..Problem solving
NETWORKING

6 In my opinion the idea could have a real-world future but I believe there is a huge work to do. I think that the results suggest that something could be done but there is a long route ahead. Personally, I will not be involved in the future of the project due to many reasons. However, I would like to stay in touch with CBI@CERN.

..Energy
..Entrepeneurship

7 Personally, I did not like at my topic in the CBI. Normally, I work a lot when I am motivated and I was envisioning myself as one of the most motivated team member as we were about to carry out an entrepreneurial project.

..Energy
..Idea generation

However, the food topic did not keep me motivated due to the lack of freedom we had to create ideas. In my opinion, I think that CBI topic should be broad so that team could have freedom to create.

..Coordination
..Multidisciplinarity

8 I also believe that schools involved in CBI should really select not necessary their best students, but at least students that prove they have working group skills and valuable knowledge. Our designer has been probably the worst team mate I have ever had. She slowed down every decision because she never took into account others points of view. From the very beginning she proved null working group skills. Second, she was neither an industrial designer nor a graphic designer. Her experience was in advertisement. How we intend to design a product with an advertisement designer? Her work in terms of product design was abundant but very poor in terms of quality. I really would have loved to have a proper designer.

1 **CBI_16_1**

..Self-awareness for professional
..Communication
..Multidisciplinarity
NETWORKING
..Self-awareness for professio

2 The experience I have had during the CBI course has been very satisfactory: I have learned a plethora of things that I am sure will be very valuable for my future professional career. From how to treat with people who has not the same background as you in the team to how to contact and treat interesting people for the project, the learning outcomes of the project are both very valuable and very sought in the professional world.

..Self-awareness for profes
NETWORKING
..Multidisciplinarity

3 But the knowledge I have acquired not only reduces to professional skills: I have also grown as a human being (both because of the topic of our project and also by treating with people of very different cultures and backgrounds).

..Multidisciplinarity
..Self-efficacy
..Communication
..Leadership/Initiative

4 I think that I have had a quite important role during the development of the project: not only in the technical part (that, as an engineer, is the part I am supposed to have more influence in) but also in all the other phases of the project. From the very beginning of the project (in the need finding and, what is more important, in the moments where we decided how the group was going to organize and work) I have spoken my mind and exposed my thoughts of what I thought it was better for the team.

..Communication

5 This fact of exposing my opinions (strong opinions, I admit I can be a little bit stubborn sometimes) and “fighting” for them caused, at first, some frictions between the group (as there were confronting visions in almost every aspect of the project), but overall I think that it was enriching for the group and contributed to the success of the project. Even more, we all as a group finally found a way of accommodating all the strong personalities present in the team (that are not a few), and I think this finally increased the strength of the team.

..Problem solving
..Technical solution/Tec
..Business sense
..Leadership/Initiative

6 The part where I probably contributed the most was probably in the design and development of the physical prototype of the hub, thanks to my telecommunications background that made me the most suitable for building it. But again, I want to stress the fact that since I started the project I was convinced not to be relegated as simply an engineer that should build what the business people decided, and I tried to act accordingly speaking my mind during the whole project.

..Self-awareness for professional
..Self-efficacy

7 So, in a nutshell, the CBI course experience has been very valuable for me, as I have been able to learn a lot of things that I could not have learned by doing a normal university course. Overall, I think that my role and my contribution to the project has been quite important.

..Problem solving

8 Although our concept (Electree) is very defined in terms of what it

..Problem solving
..Problem solving
..Technical solution/Technc
..User awareness
..Business sense
..Technical solution/Technology

should do and its key features and benefits, the physical end product is far from being done. The technology is more or less defined, but aspects as the accommodation of the product to the harsh conditions at refugee camps, the energy distributing policies or the development of a PCB for the electronics of the hub are still not clear. As a consequence, time (and money!) is needed before being able to deploy Electree in the field.

NETWORKING
..Entrepeneurship
NETWORKING

9 During all the duration of the project we have received very good feedback about our idea, and some people have shown their interest in supporting the further development of the project, so it is not impossible to think that the project can be developed after the end of CBI. We have already contacted a few people, and we are setting interviews in order to increase the visibility of the project and, as a consequence, raise the interest and, eventually, get funding.

..Business sense
NETWORKING

10 Personally, in the very short term I am not ready to work full time on the project: next semester I am going to the US to do my final degree thesis. But, as everyone knows, things evolve slowly and even if the project continued it would possibly start developing in the beginning of the next academic course, when I would be probably free again. In this case, my role in the project would depend in a lot of aspects that right now I cannot foresee: will we have investors interested in the idea? Will we have partners able to help us? Will I be offered another job that could be very interesting for me?

..Social impact
NETWORKING
..Business sense
..User awareness
..Entrepeneurship
..Uncertainty manag

11 So, summarizing, I think the project has a real potential for being further developed and, eventually, reach the field and have an impact on people's life. The path for this is long and, what is more important, help (not only economically, but also technologically and in the knowledge of camp's conditions) is needed. Personally, I am neither convinced nor unconvinced to continue the project: my continuity will depend in my personal situation and also in the conditions for continuing the project.

..Self-efficacy
..Communication
..Self-efficacy
..Self-efficacy

12 As I have already exposed, I am very proud of the outcomes of the project and also of my contribution in its development. As already explained, I was convinced of speaking my mind during all the project and not only when talking about the technical part, and I think I have accomplished it. So, as a consequence, I am pretty satisfied with the direction the project took and its result.

..Technical solution/Technology
..Time management

13 But, as it is unavoidable, I would have liked to do some things differently. For example, I would have liked to spend more time in the development of the prototype instead of losing too much time discussing things that, at the end, turned out to be unperceived. Related to this, I think the time management (personally and also of

..Time management

the whole team) could have been better.

..Experimentation
..Communication

14 I would have also liked to explore other solutions that the rest of the team did not consider valuable (such as the pee batteries or the kinetic playground), and maybe I was not good enough at exposing why I thought the ideas were valuable.

..Leadership/Initiativ
..Self-efficacy
..Social impact
..Problem solving
..User awareness
..Leadership/Initiative
..Communication

15 Nevertheless, overall I think the development of the project is quite aligned with the direction I wanted it to go (the development of something useful, innovative and readily deployable), so I think I did a good job in expressing my opinions and convincing the rest of the team.

1 # CBI_16_2

..Self-awareness for professio
..Multidisciplinarity
..Energy
..Leadership/Initiative

2 This project has been an amazing experience. I have grown as a person and I have learned lots of useful things. My role inside the group was as an engineer but I had the chance to implement my role and learn from the others. The environment and the methodology of work were the best and I was motivated all the time. I met new friends and we shared from stress to happiness situations.

..Self-awareness for professional

3 Design thinking is a methodology that I had never tried before. After this project I see that it is a useful way to make things happen. Next time I find myself using it I will be more confident and I will know what to do in each situation.

..Coordination

4 After all, I am very happy with the team I had and with the work we did all together. We were a team that came along very well.

5 The future of our project is not clear yet. For me I would like to continue it in some way if my other teammates want to. But since I will go out for an Erasmus project next semester, I think it would be difficult.

..Self-efficacy
..Self-efficacy

6 At the end, the whole project has surpassed my initial expectations in a very positive way. Although I had no experience with design thinking, I think my contributions on the project were useful and I dedicated my time to it.

7 To conclude, I have no more words to tell how positive this experience has been for me as an engineer and as a person.

CBI_16_3

2 My personal reflection about the project and the CBI course has been changing along the months really much, in the same way that my contribution and the learning experience did. This was, for sure, because of the project nature.

..User awareness
..Investigation & Knwoledge d

3 Finding a way to help people in the physiological recovery process after a traffic accident was not easy and, since the team was not composed by medical/ physiological specialists, finding and contrasting information was difficult.

..Investigation & Knwoledg
..User awareness
..Uncertainty management
..Uncertainty management
..User awareness
..Uncertainty management
..User awareness

4 We had plenty of interviews with doctors and victims and, for sure, we learnt a lot from them, but we had a “problem”: All the victims had different problems and came from different scenarios. That meant that one thing could be a huge problem for one victim but, at the same time, do not molest other kind of victims, for example, dealing with law/insurance was a big problem for some, meanwhile for others it was straight forward. Also, depending on the type of accident occurred, some victims were traumatized and others were not, some lost legs or arms and the others did not, some had mental problems after the traffic accident and others did not, and a long etc.

..Uncertainty management

5 In conclusion, we had a wide scenario with many different problems and not that many possible solutions.

..Social impact
..Uncertainty management

6 We wanted to help the maximum number of people, not just ones in a specific situation, but they were too different.

..Idea generation
..Energy

7 Thus, we kept ideating, learning about the problem and imagining possible solutions much more time that this was supposed to last. Actually, we kept changing our solution until the last week!

..User awareness

8 We were thinking many times that our solutions were “cold” and people, after traffic accidents needed “warm”. I actually felt bad and I was even sad at some point because of that, I did not like at all the idea of technology solving or trying to solve this kind of problems since, from my point of view, people and warm is the most important thing in this kind of difficult processes and situations. Handling all that “sad” interviews with victims was not easy at all for me, past suffering could be seen though their eyes.

..Idea generation
..Uncertainty management
..Problem solving

9 After many weeks of ideation and thinking I was feeling really frustrated: The solutions that we were thinking in were not appropriate or too impossible to do (at least in less than 50

..Idea generation
..Uncertainty management

years), I could not create any idea that could be useful, doable in the near future, and warm for the victims to use.

..Problem solving
..Technical solution/Technolog
..User awareness

10 We though in solutions for preventing people to feel sad in the hospital, like VR travelling, but I could not feel that kind of solutions useful for them, since we were actually making them to live in a lie. Without that VR googles, probably they will not be able to travel around those places; they could feel sad realizing about the places that they would never be able to visit in person.

..Problem solving
..Idea generation

11 We could not find an appropriate solution, at least not a solution that I liked, and I was not able to do a single engineering thing, all the team was just ideating and ideating.

..Problem solving

12 Just in the first days of the last stayed at CERN we realized that, since we were not really able to solve people's problems with technology (too cold) and we were not able to help all the victims with the same technology, maybe we just had to make them to help themselves. Just providing a way for them to meet, share warm between them, independently of which kind of problem they had after the accident.

..User awareness
..Social impact
..Problem solving

13 Then, we were not directly helping them, but providing a bridge between them, so that they could help each other. I started to feel more positive, since I could saw that we were not acting cold and it could actually help them really much.

..Technical solution/Technolog
..Experimentation

14 Then, I started to do engineering so that we could have the prototype: I had no idea about VR but with some effort, I could do the prototype work nicely after those 2 weeks at CERN.

..Uncertainty managem
..Problem solving
..Uncertainty managem
..Idea generation

15 After all those weeks of ideation and internal frustration, I could so something useful. I have to say that I would have preferred to do more hand on job, more engineering stuff, since I would have felt more useful for the team: During the first 2.5 months all the team members had no role, just "ideators" it was just in the last weeks when we stared been engineers/MBAs/...

..Self-awareness for professional
..Multidisciplinarity

16 Even though I learnt quite things, probably not engineering things (apart from the last weeks) and I think, now, I understand better the way of other people thinks. It is interesting to notice how MBAs/Engineers/Designers think in different ways between them but similar between they subset.

17 Regarding to the future of this project, I am not really sure if we are able to continue working on it. It is quite futuristic (VR is not available for every budget), we are not experts in programming

VR and it is based in the American system of heath care, so impossible to do (at least by the way) in Spain.

..Coordination

18 Even though, in the team, we collaborated really well between us. If we had to continue the project, I would definitely prefer continue it with all of them.

..Investigation & Knwoledge d

..Multidisciplinarity

..Technical solution/Technc

..Multidisciplinarity

19 To sum up, I would say it was an interesting and stressing experience. I learnt a lot about the way of gathering information about one topic and about how people with different background work, among many others. Even though I would have preferred to do even more engineering, and that we all had the same role during the first 2.5 months I would say that it was really important to have people from different backgrounds, since the way all together think is much better than the way that only one does.

1 **CBI_16_4**

..Self-awareness for professional
..Multidisciplinarity
..Self-awareness for professional

2 CBI in all its aspects has been an enriching experience. On one hand, because it gave me the opportunity to discover for first time how design thinking worked, for first time I was in a process of researching, needfinding and ideating, which was really different of what I was used: my starting point had always been the construction of the prototype, and not the process of how arriving to it. On the other hand, the chance to combine my job as engineer with other people not only from other disciplines but with different ages (Itsuma, fifteen years older than me) and different cultures (in fact, in our team we were only to SpanishDborn) has opened my mind and my way of thinking has grown. In fact, I am sure this is something I will find in all my future jobs and I am glad I have already fight it

..Uncertainty management
..Self-awareness for profes
..Self-awareness for profes

3 For first time, I was not given the problem in order to solve it, I had to find the problem to then be able to solve it instead. I had to think the questions to be able to find the answers. So, it make me realize that that was the difficult part and how important it is, is the part that I will meet in real life, in real jobs problems.

..Business sense
..Multidisciplinarity
..Experimentation
..Investigation & Knwole
..Leadership/Initiative
..Self-efficacy
..Leadership/Initiative
..Technical solution/Technc

4 Furthermore, working with people with different studies than mines has allowed me to learn about their work, now I understand a little more about business and I am able to use with more confidence design software, as Illustrator, Photoshop, which maybe one day I will be grateful to know how to use it. However, in order to build our prototypes, I had to do a huge research and learn by my own. For instance, I was forced to learn in one day how to programme an Android App, I had never used Android Studio nor any similar tool to develop apps for Android but I achieved to programme a not very complex app to display our prototype. I also started picking up how Unity worked, but I realized due its learning curve, trying to programme a VR Game for our prototype was maybe too ambitious, at least with the amount of time we had.

..Communication

5 I have been talking about learning from other disciplines but I also have learned a lot from my software engineer teammate, Carlos, who has more experience than me and helped me when I got stuck. Besides, I had improved a lot my English level, when I started the course I only had the first certificate which at beginning was a deterrent to express my ideas in public, because I was too slow explaining them that people disconnected, paying little attention to what I was saying. Definitely, I forced myself to improve my English (combining them with English classes in Barcelona) and at the end I could express my ideas much more fluent.

..Idea generation
..Idea generation

6 Well, personally, I think I brought the realistic part when the ideas were going too far, too imaginative. Unconsciously, my mind tried to make it feasible, so mixed with the other crazy ideas, we found futuristic things which in someway could be done.

..Critical thinking
..Time management
..Experimentation
..User awareness

7 About the result of the project, I am not completely satisfied, I believe that if we had had more time, our idea would have been clearer. I would like to continue with the project if the idea focuses on exposure games which I believe is the one with more possibilities. In addition, I would really have like to test final Proton with real users in a comfortable environment and obtain real feedback, and see how much it can help. Then, I would be more confident on deciding my attitude in front this project. However, now I am still undergraduate and I would like to prioritize other aspects of my academic formation which in someway are incompatible with the idea of continuing with the project.

..Business sense
NETWORKING

8 Moreover, the half of the team is not willing to continue and the other two may be would not like to follow the same direction. So we would need lots of experts, but financially is very difficult.

..Self-efficacy
..Technical solution/Technc
NETWORKING
..Technical solution/Technology
..User awareness
..Uncertainty management

9 It is true that I have been forced to learn many things on my own to build the prototype, but I have missed to continue learning something from the telecommunications' field, as I think it is done in other advanced projects. And I think the opportunity was there, that the technological facilities offered by CERN to learn a lot of things, with our challenge, were difficult to take advantage of. In fact, I would have preferred a project that did not have so much weight on the social side, and had a more technological approach. Especially, our challenge needed a warm solution, in fact it was received as slaps every time we presented an idea because it was too cold. And in the end getting our solution was a big challenge.

1 # CBI_16_5

..Coordination
..Leadership/Initiative
..Critical thinking
..Coordination
..Communication

2 I tried to help the team as much as possible, so I feel that at some point I could have pushed the project to another direction but instead I defended another idea in order to unlock a situation and move forward as a team. Probably I should have taken more responsibilities in the work to be done. I have learnt a lot about team structures and how important is communication inside a team.

3 It would be great to develop further this project, but I do not really see the potential needed to start devoting my time to it. So unfortunately I guess that the DALI project and Jamie will be abandoned.

..Leadership/Initiative
..Coordination
..Communication

4 Basically the generation of conflicts inside the group prevented me to push to my direction, I only tried to impose my ideas if I had very clear that I was right. Even though in my challenge it was easy to have ideas before starting, I think that our team did the exercise of leave them apart. Doing that I think that we were able to listen to each other and from that started to create the final concept.

1 **CBI_16_6**

..Uncertainty management

2 As an engineer until the end I didn't feel that I had a very defined role, during the first 2 thirds of the process (diving by visits to CERN) I felt like all the other teammates had their roles much more defined, we as engineers didn't. I tried to participate in all the activities programmed and discussions, as my teammates have told me and I know at some points I was out of some of the discussions since they weren't very interesting for me and I believed that I couldn't add much to the discussion, at that point I unintentionally disconnected. I actively tried to pay attention and participate but sometimes it didn't work out.

..Critical thinking

..Communication

..Critical thinking

3 By nature, I'm a realistic person and when we were having some discussions at the beginning I had to make an effort not to express my opinion, since it meant saying "no" and that wasn't well received at 2/3 of the process. Also, regarding to that the designers were very reluctant to hear critics about anything, they don't like hearing "no's" since they say it destroys the design thinking process, and also they tend to confuse critiquing something with critiquing someone. These came up in the last feedback session by other members of the team also.

NETWORKING

..User awareness

..Technical solution/Technology

4 My contribution to the project has varied through the different stages of the process. Since my personal experience with people with IDD I was able to give a perspective very hard to acquire if you don't touch the problem very closely, also that allowed me to set up different interviews with people, that gave us very good information. At some points, also it was very hard for me to join some interviews/meetings with the rest of the group due to all the workload from school, I wish I would have been able to join more. At the end I felt more useful because I could do more of what I know, regarding to all the technical part of the project.

..Uncertainty management

..Self-efficacy

..Self-awareness for professional

..Multidisciplinarity

..Coordination

..Leadership/Initiative

5 Until the end (the last week at CERN) I wasn't very happy with the outputs of this experience, I missed a lot a real "PAE" experience, at some points it was very frustrating. But now that it has ended I am very happy of the outcome, I will think twice before doing it but it has been a very good experience. PAE would have given me a 1% of what this has given me, from English, meeting new people with different roles & ages to visiting CERN, having to prepare presentations for a bunch of different people. This project has given me a better understanding of how human relations work, teamwork, that people work in different ways. It's hard to explain all the different outcomes, but now I will feel confident directing a

..Multidisciplinarity
..Coordination
..Leadership/Initiative

multidisciplinary team in any company. And it has been a lot of fun.

..Technical solution/Technology

6 At this point our team has decided to have a break until January and then sit and talk about it again, then we will see what comes out of it. For this project to continue it needs a lot of software development to achieve what we dreamed, and for that we will need developers and the money to pay it, I don’t like that type of software (speech recognition/detection) so I won’t take a big part working on that I would just help the rest of the team manage the project and maybe be in charge of people, but not actively “code” for it.

..Technical solution/Technolog
..Business sense
..Uncertainty management

7 I wish that we could have got more feedback about the “feasibility” of our project and how interesting it is for someone to invest on it. At the end we got a lot of mixed feedback that was very confusing and didn’t give me any clue of how good the idea was and if we could pursue it with more effort. I understand that that is not an easy job, but I think that an effort could be made. Right now I don’t expect anyone to help us develop this further, I just hope that all the Teaching Team could give us their honest opinion about our idea and then some resources on how to continue.

..Self-efficacy
NETWORKING
..Technical solution/Technology

8 Regarding this part my expectations have been more or less accomplished, I’m very happy with the result. I didn’t expect some of the very very boring & useless talks that were given the first two times we went to CERN, the worst of them was the activity on “how to make a plane in x minutes”, I expected something totally different and felt totally disappointed with it. I maybe expected to do a little bit more of technical stuff in the middle of the project but it didn’t happen until the end.

1 **CBI_16_7**

2 Looking back, the contributions I made to the team were the following:

..Technical solution/Technology
..Idea generation

3 • Find out ways to make the teammates ideas possible in a technical context and tell them the difficulty of implementation. If it isn't possible then make sure no one follows that path. Also propose variations to the idea so that simplifications can be done.

..Investigation & Knwoledge disc
..Idea generation

4 • Go to interviews and parse the technical knowledge so it could be understood by the rest of the team. Most of the times I went with a partner either with Mauro or Franc, for them it would be easier to talk and lead the interview and then I would ask other questions that would let our ideas continue to new directions or not get trapped down the road.

NETWORKING
..Idea generation

5 • As the rest of the teammates find people to interview, contact them and write a synthesis of the meeting. Also constantly participate in the ideation process.

6 • Programming the prototype.

..Investigation & Knwoledg
..Business sense
..User awareness
..Investigation & Knwoledge disc

7 Most of the learning about the project was made during the definition, needfinding and business model creation. Investigation is just as important as interviewing, interviews only work if you know what you know what you are talking about.

..Investigation & Knwoledge disc

8 I improved somewhat searching information on the web and organizing articles. At the beginning, as it was expected, we started reading lots of articles related to maintenance and trying to find numbers to act on the most relevant problems.

..User awareness

9 A good lesson was learning how to decide when to act on interviewees opinions. Conducting interviews we started to find contradictions of what people said. For example, in one occasion someone told us machinery producers have an incentive to make machine fails, planned obsolescence style. Some weeks later there was just too much evidence indicating that wasn't the case.

..Coordination

10 In the context of teamwork I got better on

..Coordination

..Coordination

dealing with people in general. One thing I failed gracefully was trying to understand how other people perceived me, every time there was a team feedback session I would get surprised.

..Social impact

..Self-efficacy

..Problem solving

11 This project has a lot of value, I totally see it as a future industry product. Symmetra is a new way of communication that lets people transmit information more clearly by interacting with virtual objects and projecting those interactions to reality.

..User awareness

..Business sense

12 I don't really imagine this product being B2C, consumers won't read the manuals even if it''s simpler or more interactive. I would like to see it on places where people truly benefit from reading the manuals, sharing knowledge and where the learning curve is steep. The most obvious client are factories since this is what the project was focused on, but other entities could greatly benefit from it since the product empowers retaining in-house knowledge.

..Entrepeneurship

13 I would love to continue working on this project, be it as a startup product, H2020 project (probably just a dream), etc. No connected projects emerged during CBI, but If at some point I start something I'll probably give a call to Franc, Mauro and/or Arjun.

NETWORKING

14 Continuing with this project any help from CERN and UPC would be extremely valuable in the technical aspect, particularly from the C2MON team and the MCIA research institute. From the business point of view all of the ESADE professors were very helpful and offered great insight, specially Constance Lütolf.

..Coordination

..Multidisciplinarity

..Self-efficacy

15 My contribution matches almost perfectly with my initial expectations. I would just have hoped to participate more in meetings. My thoughts often weren't aligned with that of the teams' but I'm really glad about this, pursuing the things I wanted would probably have lead to a worse outcome. This just reflects the better capability of a team to make decisions as a whole. I'm happy with the direction the project took and how it ended.

1 **CBI_16_8**

..Self-efficacy ..Idea generation ..Problem solving ..User awareness

2 Overall I am really satisfied with the progress and the results we have obtained in CBI. I think we came up with an accurate analysis of the issues and problems in education, and we envisioned solutions in the right direction.

3 *Role*

..Problem solving ..Idea generation

4 As I am a technical person, I've contributed in taking crazy ideas that were very complex and difficult to understand and converting them in understandable and feasible things. It is positive to generate 'black holes' and creative ideas, but in order to execute them and actually help people they have to be perfected into feasible things.

..Critical thinking

5 Moreover, I think I can do good analysis at a system level and I have often played the role of the devil asking lots of questions and making sure we were not missing anything.

6 *Learning Experience*

..Multidisciplinarity ..Coordination

7 During CBI I've realised how tricky is to work in a multidisciplinary team and the differences in the way of thinking of the different professionals. I've learned to deal with very different people and to always search for a middle point where everyone agreed and felt involved.

8 Furthermore, I've gained a wide view of the multiple problems found in education.

9 *Future of the project*

..Critical thinking ..Technical solution/Technolog

10 I'm not sure our group will continue the work with DALI. The main problem I see is feasibility. It is a complex solution and requires developing content with the help of many professionals in education. It requires coordinating a lot of people.

..Problem solving

11 Regarding Jamie, the part of DALI that we did implement, I think it is definitely more feasible and we found prof from benchmarking that similar concepts do work (such as brainly.com).

..Problem solving

12 I think Jamie is a simple concept that would make a difference, and that ultimately can evolve in a more effective solution that has the potential to provide personalized education at scale.

..Self-efficacy

13 I am convinced it is a good idea and I would like to continue if there are resources. Moreover, I think it would be a good idea to continue it with Desislava and Narcis.

14 *Help from institutions to continue*

..Business sense

15 In order to develop Jamie we definitely need funding. It is the only way we can commit full time. If we had it, I would commit.

16 *Comparison with initial expectations*

..Self-efficacy

17 As I said earlier, I'm pretty happy with the results of our project and i think we found a solution that everyone understands, agrees, and feels involved in.

..Technical solution/Technology

18 In the technical aspect, we did a great job, but I feel we could have gone a bit deeper with Watson and we could have tried to make him learn from big databases (such as stack exchange).

1 **CBI_16_9**

..Multidisciplinarity
..Multidisciplinarity
..User awareness
..User awareness

2 The biggest motivation I had when I applied to do this course was the fact of doing a project in a multidisciplinary team so as to tackle the challenge from different perspectives. Working with students of other fields, such as business or design, gave me an idea of how they think and this implies that I will be awared of their concerns for future projects. A good engineer does not only have to know about the implementation, he also must think about the real demand of users. Ultimately, technology must match human needs and personally, I think that this project forced me to think much more in meeting human-driven needs than the state of art of the technology in use. In other words, I achieved changing my way of thinking in order to be capable of identifying needs and solutions for humanity.

..Leadership/Initiative
..Leadership/Initiative
..Leadership/Initiative

3 The last day, after the feedback session, my collegues frankly claimed that I naturally became the leader of the team. In that moment I realized that it was true. I was not commanding what each one has to do, but I was the one who organized and planned the activities and tasks we had to perform. I really like the fact that this happened spontaneously. We did not assigned the role of leader at the beggining instead, we bet for a flat structure and I think it worked correctly because it pushed us to take out the best of us, in my case my leadership. After finishing this project I feel lucky of the group that randomly was created I reckon a good synergy was created.

..Organization
..Leadership/Initiative

4 I reckon that one of the most essential personal contributions were in the organizational and management tasks. Since the begging, I expected to contribute in that sense because I am good at organizing and planning. I took the lead on organizing what tasks we had to do and who was the responsible of performing those assignments.

..Technical solution/Technology
..Technical solution/Technology
..Technical solution/Technolog
..Problem solving

5 On the other hand, since we did not have to deep in the communication protocols used in the industries, high technical expertise was not required. All along, I was awared of this fact so I was not surprised. However, my technical contribution has been declaring the feasibility of the concepts we built and also how can we technically implement our idea. This contribution was crucial so as to present a suitable concept at the end of the course. Indeed, I enjoyed contributing with my technical knowledge so as to determine what was possible and not just implementing a solution given the problem and the technology.

..Design Thinking
..User awareness
..Experimentation

6 Regarding my learning experience of the course, I would like to remark the fact that I certainly liked the approach proposed by design thinking process. It made me think in another way when dealing with challenges, specially in the needfinding process. I realized how

..Experimentation

important it is to deeply understand what is the real problem you are trying to tackle before starting anything else and also how useful it is to reiterate the process as many times as needed.

..Energy
..Business sense
..Energy
..Problem solving
..Experimentation

7 Right now I feel really excited about the future of this project. We created a valuable concept that can fit into the existent market. I am enthusiastic because the output of the project is a solid idea that can be implemented and it can solve an existent problem. This fact makes me think that we must go a step forward and check how we can develop the our solution proposal. From my point of view, the idea worths trying to develop it in a real scenario and verify its feasibility. If we are capable of doing so, we could start thinking about the business.

..Multidisciplinarity
..Multidisciplinarity
..Leadership/Initiative
..Multidisciplinarity
..Leadership/Initiative

8 In case that we achieve that this first implementation works, I would like to take the lead in the product development. I really enjoyed the creation and development of our concept. In this course, I learned how to work with professionals of different backgrounds and I realized that I am really good as the join of techies and business. Thanks to my technical knowledge and my deep interest in business aspects, I felt really comfortable working with both matters in mind. I foresee my role as the leader in the group, thanks to this attitude. I am able to make the techies understand that somewhat is too complex to be sold but also to business guys that their idea is not implementable, for instance. I did not declare myself as the leader as first statement, my collegues told me that instinctively I took this role during the project and the group worked correctly. I think that now we should move on as we have been doing since the results by the time are genuinely good.

NETWORKING

9 To move this project further, we would like to receive support from the coachers of the course considering that they know the project and the team. Since we have the contact details of the coachers, we are planning to contact them in the near future so as to receive specific help. Moreover, we have contacts in CERN that kindly offered us support. We took their word for it so we will contact them soon.

NETWORKING

10 Regarding the companies we met during the course, we are analysing which of them are the best so as to purpose a partnership or at least to receive some feedback to improve our approach.

..Multidisciplinarity
..Leadership/Initiative
..Self-efficacy

11 This course met my expectations from all points of view. Firstly, I learned what I wanted, avoid thinking just in the technical aspects and broaden my concerns when tackling challenges. Secondly, I could actively contribute in the way I wanted. I was eager to enhance my managing skills and I succeeded. And lastly, I want to highlight that I am absolutely satisfied with the final result presented and the performance of the course.

..Uncertainty management

12 Now, I wonder how to move all of this a step forward. Fortunately, we believe that our idea has a lot of potential, and we have a highly motivated team with a multidisciplinary skillset that is eager to discover how to proceed.

1 CBI_16_10

..Coordination
..Multidisciplinarity

2 Teamwork is certainly something quite common in a student's life, especially in the present education framework. However, in CBI I have had the opportunity to approach teamwork in a very different way I am used too. Either in the university itself or in all of the workplaces where I have been, the groups of people working were made of individuals with very similar profile, and somehow with every of them pointing at the same direction. However, here I was able to work together with people with different points of view and even aiming at different outcomes when treating the same problem.

..Multidisciplinarity
..Idea generation
..Critical thinking
..Multidisciplinarity
..Multidisciplinarity

3 At first sight, this might seem a difficulty for work to be done and the quality of it, but I realized it is actually the opposite way. On the one hand, when the team is working in defining the project and coming up with new ideas, it is certainly when different structured minds think together when big and complex ideas can be created. From my experience, a group of engineers, for example, might be discussing for a long time in a problem but the discussion would be on minor details and not on the real issue. On the other hand, when developing the project, everybody knows his or her role, so there is no overlap or conflict problems. And, at the same time, which is one of the most important things I have learned here, working with somebody with another expertise at your side actually can give you much more interesting insights than a person familiarized with the subject.

..Multidisciplinarity

4 Therefore, I have realized diversity can only sum up, and teaches you that anybody can contribute to any aspect of the project, no matter his or her expertise.

..Self-efficacy
..Energy
..Social impact

5 I believe that all of our team was quite overcome for the success of our project. Indeed we believed (and we still do for sure) in our project, but we could not actually imagine this outcome. This has certainly taught us, on the first place, to aim higher in our expectations and the future of it.

..Social impact
..Social impact
NETWORKING
..User awareness

6 As an engineer, I obviously expect to become an active part of the development of a product that can actually help thousands of people. At the same time, having the change to work with companies and institutions such as UNHCR gives this an amazingly interesting perspective, since many of the institutions that have shown interest in our product are also concerned on how they could actually help us.

7 Starting from the end of the question, with this project one does not modify his or her "initial

8 expectations" to push the project in a certain direction.

NETWORKING

9 When you are put in an environment like this one the opportunities that the people in your group, the teachers, CERN faculty and all the contacts you might come up with is so broad that your "initial expectations" end by being just a starting point.

..Experimentation
..Investigation & Knwoledg
..Uncertainty management

10 So, looking backwards, I just can say that all the contributions at the beginning must be taken very seriously, because without a base nothing can progress. However, one must expect that the outcome of the project could be completely different from the initial thoughts, because this is about using the tools to build, but also, and more importantly, to discover.

CBI_17_1

..Self-awareness for professio
..Self-awareness for professio
..Critical thinking

1 After doing the CBI course, I think I have lived through a truly important experience, not only in the personal aspect but also regarding the professional area. From what I experienced, I think this course is a fantastic approach to the real-life situations that we may have to confront in a few years. The project we had to work on (Power Index), in my opinion, was a really ambitious proposal, that could work only in an assumed situation. The current publication services for research papers lack of transparency and openness, and the whole system is completely enclosed. For us as Team Margulis, to make an improvement in this situation, was a huge challenge.

..Idea generation
..Problem solving
..User awareness
..Problem solving
..Idea generation
..Problem solving
..Business sense
..Technical solution/Technology
..Coordination
..Multidisciplinarity

2 I think we all could contribute with some great ideas, most of them ideas to tackle some specific problems we had discovered while doing interviews. But when envisioning the whole system and thinking about how to open it up, I think Tom and Jessie, both the students from ESADE, had the greatest ability to ideate something else. From this, I think I learned the basis of how to design a product so it can solve the situation, serve the right people and be sold to the correct institutions. In our case I think this was the core of the project, in which I was not able to help so much because my lack of experience in this area, but instead I think learned a lot from my teammates. When doing the proof of concept I think I was able to meet the team's expectations and that Sergio and I divided appropiately the work to do so we could meet more or less each of the main technological requirements of Power Index. Finally, in the team context, I think all of our personalities were really different but also were complimentary and each of us could contribute with a unique skill and fill a certain aspect.

NETWORKING
..Social impact
..Problem solving

3 Thinking about the future of Power Index, I think it's a product start working on right now as a startup, but I don't think it is going to continue. This is because the topic is really difficult to work with and the product requieres a lot of time to polish so it can be finally successful, and currently none of us has enough time. I really think we could get some universities to recruit using our product and some of them would be really willing to collaborate; and even also a lot of researchers would support our product if we made it fair for them, transparent, open, and up to be constanly changing and adapting. Then, it would fulfill the first objective of Power Index: start opening up the current system, unifying all the scientist communities, and giving more possibilities to further innovations in the publishing services.

..Entrepeneurship
..Leadership/Initiative
NETWORKING

4 Personally, I am more motivated to pursue a career as an entrepreneur, since I have learned a lot from the seminars, my teammates and the project itself; but I still don't plan to since I want to focus on my studies for a couple more years. I hope I still have the support from the professionals I met at CERN if, in the following years, I need their help.

..Energy
..Idea generation
..Technical solution/Tec
..Problem solving
..Experimentation

5 Lastly, to reflect on the direction of my contributions, I have to say again that I considered this project one of the most challenging and difficult to get the correct solution to fit everyone. Therefore, I had more innovative ideas or specific solutions, but they didn't fit the whole size or the great ambition of the team. On the other hand, I could manage to impulse the project to have a more technological approach, so it had a more realistic look and also to be able to work with different technologies and experiment with them, to know what these could

..Technical solution/Technc

..Problem solving

..Experimentation

6

offer now and what could offer in the future.

Finally, thank the teachers at UPC for giving me and my university colleages the possibility to attend this amazing course and experience.

1 **CBI_17_2**

..Multidisciplinarity
..Self-awareness for professio
..Energy

2 My role during the CBI program was to be one of the engineers of the group, but during the three month I have participated in every step of the process as any other team member. Only in the last two weeks, when we were at IdeaSquare, each role was differentiated. In my case I had to do the engineering part but after that I could manage to contribute to the presentation. I think that my main contribution to the team has been the 24/7 good mood and willingness to have everything done.

..Multidisciplinarity
..Idea generation

3 Thanks to this project I have been able to connect with other backgrounds people and see how they work and the way they think, by that I'm trying to say that working with people that are not the same field as you helps you to think out of the box and change your mind easily.

..Self-efficacy

4 Personally, I see that our project has potential to be out there in the market. What I feel that after three month of work and research done, it's hard to continue this project just after CBI because the majority of the team is finishing their studies and maybe the projects need to wait at least one or two years before they can be carried out again.

..Self-efficacy
..Multidisciplinarity
..Self-awareness for profes

5 In the hypothetical case that the project is carried out and it's successful, I see my myself a little bit apart from the full technical side, I think that using my knowledge and mixed with possible future experiences with teams like the CBI one, I can offer more than just be in the tech part.

..Multidisciplinarity

6 Before starting the CBI course, I thought that this would consist on some kind of project where I had to just do my job as engineer and get a pretty result to show off, but now I see it totally different. In the team there was no division between the engineer, the designers or the MBA's, everyone was contributing with their research and feelings and there was only a clear difference at the last part of building the prototype and doing the presentation.

..Coordination

7 What prevented me to push the project on my prefered direction was that I thought I need first to connect with the team and see their points of view about the path to take and that it would be interesting to work in something different I'm use to work and discover unknown fields.

..Self-efficacy
..Multidisciplinarity

8 After almost four months, I can proudly say that we did a good job and managed to create something new and innovative and also I feel that what I have learned from working with designers

and MBA's, like their ways to work or thinking, is something that I could not have learned it at the university.

1 **CBI_17_3**

..Uncertainty management
..Multidisciplinarity
..Coordination

2 Despite being one of the engineers of the project, part of my effort was directed towards setting myself in situations I was not comfortable or inexperienced. During the development of the project in the CBI curs I have learned mainly how to work in a multidisciplinary team. Teamwork is not easy as you need to slowly gain trust your teammates, listen to them and their ideas but also defend mine.

..Investigation & Knwoledg
..Design Thinking
..Problem solving

3 The research phase of the project was one of the most enriching parts of the CBI program. After applying the design thinking methodology I can now see the importance of really know and understand the challenge, who are the stakeholders or what will the solution provide in order to end up with a useful and worthy solution.

..Communication
..Self-awareness for professio

4 I also have had the opportunity in the project to lose my fear to speak in public thanks to the numerous times we had to present.

..Energy
..Coordination
..Multidisciplinarity
..Energy
..Self-efficacy

5 Finally I would like to say that due to a great group quimic I was able to be participative and get involved in a great measure in the solution of our challenge. I tried my best to get out of my comfort zone by discussing and learning from every aspect in the project, from economics to design. As expected I put a lot of effort during the intensive week at CERN or even weeks before in Barcelona to develop a prototype worthy of the CBI program. Xavi, the other engineer in the group and me are very satisfied for the results of the prototype.

1 **CBI_17_4**

2 I would like to divide my personal reflection about the Challenge Based Innovation course in three parts: what I expected, how it developed and what we achieved.

..Uncertainty management

..Self-awareness for professio

3 From what we were told during the Economy & Management lecture when we were presented the possibility to take part of the CBI course, I pictured a different scenario: a more technical project with less participation in topics outside our academic knowledge. Later I found that part interesting because we got to learn in areas where we may not have the chance again and explore different procedures than what we are used to as engineers.

..Uncertainty management

..Leadership/Initiative

..Communication

4 Now talking about my project. My interest was extremely high when we were introduced to it but my interest kept decreasing as the course developed both due to constant changes in the challenge definition and other group members not taking into account both Marc's and mine technical knowledge when technical-related discussions occurred. When we faced the nuclear radiation inspections concern I took a very participative role inside the group, leading in research in both technical aspects and interviews or visits but I felt that all what I brought in was not taken into consideration when decisions were made so, as a consequence, my interest in the project decreased. Our final project did not achieve my expectations at the beginning of the course.

..Problem solving

5 As stated, although the final outcome was very well presented a carefully polished it did not achieve my expectations from a technical point of view whether it's because what I pictured was not what was supposed to be developed under this course, or because our team did not perform as expected.

6 Although the project did not fulfill the technical expectations, the overall sensation after the course is very positive because I got to know excellent people and an excellent relationship among my engineering comrades emerged. I value a lot that part of the course, as well as getting to know how people in other fields than engineering work.

..Uncertainty management

7 What I think could be improved for the next edition of the course is giving a more accurate description of the course before the students apply for it, be sure that there is enough resources to find problems related with the challenge given, get the non-engineering students to take into consideration the technical knowledge from the engineering students, and last, but not least, try to make the weekly lectures more related with the development of the challenges and try to move them to the morning to have all the afternoon for group work.

1 CBI_17_5

2 Firstly, I have to say that it has been a nice experience to work with people from other disciplines. They had different visions about how to solve problems and abilities that engineers like us don't have.

..Multidisciplinarity

3 The most important and valuable part of my contribution was made during the first phase of the project. I really enjoyed going to interviews with scientists, doctors, engineers and people from the administrative world (mainly people from Barcelona's city council and ASPB). Again, from these interviews I take a lot of learnings: I've seen that generally it exists a lack of communication between the society, the public administration, and the scientific community; I've also understood that there are a lot of different points of view and solutions for the same problem and in general I've met a lot of highly motivated people, that were surprisingly happy to contribute to this project.

NETWORKING
..User awareness
NETWORKING
..User awareness

4 During the last part of the project, I've contributed to the technical part with Oriol, mainly preparing the electronic part.

..Technical solution/Technology

5 Nevertheless, from my point of view the proposed solution was not the best. We struggled during the last weeks to focus on one prototype, and probably the final decision was not taken based on technical or objective facts. During these last weeks we had a lot of interesting team discussions about possible solutions, that we finally discarded because they were already developed or were not viable. However, focusing on indoor air pollution had a strong justification, based on all the interviews and research (articles, dossiers and books) done.

..Critical thinking
..Experimentation
..Idea generation
..Problem solving
..User awareness

6 For me, this prototype is still in an early stage. The concept could be interesting, but some technical issues have to be solved, like the light source that could provide UV and infrared radiation. A lot of interesting ideas came during the project, and specially during the interviews, that were not necessarily related to pollution, but could be explored. An important part of the interviewees were very interested and could be used to develop a project.

..Technical solution/Technology
..Idea generation
NETWORKING

7 Looking back to this project, I accomplished one part of my expectations: I've met a lot of interesting people in CBI and during the interviews and conferences, and I had the pleasure to work at CERN, also accompanied with a nice group of engineers from UPC. On the other hand, maybe I expected more collaboration with CERN, and I was clearly disappointed during the first phase of the project, when Oriol and I did a lot of research and interviews, but team decisions during Thursdays were sometimes based not on this technical and objective information, but on subjective thoughts. We had some discussions in our team for that reason.

NETWORKING
NETWORKING
..Leadership/Initiative

8 Overall, it was an interesting experience that I would recommend to someone that wants to explore different ways of thinking, and learning

..Idea generation

..Idea generation

9

how an idea is "created" and developed.
Thanks!

1 **CBI_17_6**

..Self-awareness for professio
NETWORKING
..Multidisciplinarity
..Multidisciplinarity
..Experimentation
..Idea generation
..Technical solution/Technc
..Energy

2 I am very grateful to had the opportunity to work in a project like Challenge Based Innovation because it was a real-work project powered by such an important organization as CERN. It was a great experience for so many reasons. First of all, I had the chance to meet new people from all over the world and from other disciplines. I think that we are not used to work in projects like this in the university and it allowed me to know what it is to be part of a more realistic project and participate in the whole process of research and ideation that most of the times we don't see as engineers because we just do the technical part of the projects. Therefore, it was challenging and that motivated me to work hard.

..Coordination
..Technical solution/Technology
..Communication
..Coordination

3 Having said that, I would like to mention that I am very happy with my team. I believe we worked as a real team and that was reflected in our results. Each one of us gave his best and contributed positively to the group. Personally, I tried to handle the technical part the best I could with Arnau, the other engineer in my team, and we tried to always explain and share our decisions with the rest of the team so everyone could give their opinion. That way the whole team participated in all the decisions.

..Organization
..Technical solution/Technc
..Technical solution/Technc
..Communication
..Multidisciplinarity

4 Also, for the technical part, we divided the tasks accordingly to the expertise of both engineers in order to make things more comfortable for us and get better results. That's why Arnau (computer science) took charge of the blockchain (software) and I (telecom) was in charge of the fingerprint sensor (hardware). Still, the good communication made it easier to work together and get the expected results. Besides the technical part, I tried to helped the other teammates in their work related to their field of expertise.

..Multidisciplinarity
..Multidisciplinarity
..Problem solving
..Idea generation

5 Moreover, I think each one of us contribute in a different way because all of us were unique and with different opinions, but the combination of all the points of view turned out very satisfying results. Furthermore, I realized the importance of working in a multidisciplinary team because every discipline contributed in a different way, but all of them were important and made the whole process much easier. That is one of the reasons why I think the research and ideation of our solution was that accurate and complete.

6 Thinking about the future of this project, if our team decides to

..Coordination
..Social impact
..Self-efficacy
NETWORKING

continue working on it, I would like to take part of its future life. I felt very comfortable working with them, so I would have no problem to continue to do so. Additionally, I believe we had a very powerful idea that could make a difference in our society, so I would be really proud if it would be implemented someday. However, I also think that due to the dimension of the whole system, we would need external help in case we wanted to make a step forward.

..Uncertainty management
..Idea generation
..Time management
..Technical solution/Technc

7 Finally, taking a look back to the beginning of the project, I would say that it did live up to my expectations. I must admit that I had my ups and downs during the whole process and there were moments where I was a little desperate because I thought we were wasting our time. The research and ideation part seemed a little too long while working on them. However, taking it into perspective, I realized that those parts are the critical ones and they need to be done super accurate in order to obtain good results. Furthermore, in my opinion, I would have liked to have more time to work on the prototype because we could build something more thorough and complex.

..Self-efficacy
..Coordination
..Multidisciplinarity
..Self-awareness for professional
..Self-awareness for professio

8 To sum up, I am very proud of team Wu, how we managed the whole process and the final results we obtained. It was very satisfying to work with people from other disciplines that appreciate your contributions. Also, it was an enriching experience that made me learn lots of things of real-life projects that I probably would not learned at university. It made me understand that we are prepared to work in real projects because we know how to do more things than what we use to think and, more importantly, I realized that collaboration and a good environment are key points to get successful results.

..Self-awareness for profes
NETWORKING
..Uncertainty management
..Entrepeneurship
..Social impact
..Uncertainty management
..Technical solution/Technology
..Idea generation
..Investigation & Knwoledge d
..Experimentation
..Problem solving

1 **CBI_17_7**

2 I am very glad to have been selected to take part on this project which has represented a great unique opportunity to experiment a real-work experience in an unbeatable scenario such as CERN. It has been very challenging to go out of the comfort zone and experiment for barely first time a real project that differs from the closed ones that we are used to do at university. This kind of initiatives, approach the entrepreneurship to students and push them to develop solutions for the great problems that we nowadays have. As a member of Team Carson, I admit we have gone through a lot of ups and downs which sometimes led us to think that no solution was possible for our extremely broad challenge. Despite of the fact that the technical part was almost done in the last trip to CERN and it cannot be as elaborated as the projects done at PAE, I really appreciated to take part into each of the development phases such as ideation, research and prototyping. However, I am really happy that both engineers in Team Carson, have achieved all the requirements of the conceptual product and successfully solved all the troubles that we found.

..Self-awareness for professional
..Self-awareness for profes
..Multidisciplinarity
..Idea generation
..Entrepeneurship

3 In my opinion, this kind of projects should be more frequent in the whole career as it radically changes the way of thinking, opens your mind to new and future paths and enriches your knowledge in different areas. Working with multidisciplinary teams is thought to be essential in the professional environment, nevertheless, it is atypical to find coherence in the academic phase. During the whole project, we went through nice ideas that can be further implemented but, apart from any project, I would like to remark the experimented entrepreneurship that led me to think in a future developing similar ideas.

..Uncertainty management
..Self-efficacy
..Multidisciplinarity
..Multidisciplinarity
..Self-efficacy
..Self-efficacy

4 At the early stages of the project, I have to admit that I was a bit disappointed when the engineers were doing research and it seemed not to be appreciated by the rest of the team. Moreover, all the possible paths of our project end up to overhead us in some occasions. Nevertheless, it has been really satisfactory to realize that all the knowledge that we acquired along the degree let us to do almost whatever we want. I also would like to make emphasis in the co-learning process that occurs when you work with other disciplines. I have learned tips about team management, design techniques and, what is more important, I saw that what seems easy to us can be seen as really difficult for others. This tiny detail enhanced my performance as I felt very

..Self-efficacy

appreciated when my team mates where astonished on what engineers are able to do.

1 # CBI_17_8

2 Let’s talk about the CBI experience. I have worked in Team Sutherland, with Kenza, Ricky, Marc and Edward. With these people, we have built a great working relationship, which has helped to create SENTRA.

..Coordination

3 From my point of view, there has not been very intense roles, but we all took different roles during the project. I think I contributed a lot more in the last part of the project (the prototyping part), but I also worked hard in the *ideation* part, although I didn’t like it a lot. What I liked most was having the opportunity to bring new ideas to my team and that they were listened, as all members of Team Sutherland were open-minded and wanted to listen to new ideas.

..Multidisciplinarity
..Technical solution/Technolog
..Idea generation
..Idea generation

4 My learning experience have been awesome. The first 2 months I felt a little bit useless (like all the team), because we did work, but we did not have a concrete goal, so it was sometimes confusing and not motivating. But then, when we focused on the idea of the *haptic suit*, it became a motivating project where all of us were focusing on.

..Uncertainty management
..Problem solving

5 To me, working with students from other disciplines (Informatics, Business and Design students) have been really enriching. I am used to work with “telecom” teams, and now, that I was the only one in telecom, I learned other ways to work. And these new manners of working were incredible, actually I have already used some of them.

..Multidisciplinarity

6 The project itself (SENTRA) was quite motivating. This is probably because of the problem we wanted to solve. Although I find it a really interesting project, I think that I would need to improve this idea more in order to continue with this project in a near future. I don’t see myself working on this exact project because I don’t think it’s innovative enough to dedicate so much time. However, as I said, I think the idea is very good, just that it needs to evolve and improve from my point of view. If I/we could improve it, I wouldn’t mind working alone or with the other team mates. However, we are taking different paths in our lives and, unfortunately, this will be difficult to follow.

..Energy
..Critical thinking
..Critical thinking
..Critical thinking

7 To finish with my personal reflection, let’s compare with my initial expectations. Before starting CBI, I thought that the prototyping part had started before. This is probably the reason why I got a little bit less motivated the first two months. I thought

..Uncertainty management

..Uncertainty management

..Self-awareness for professional

that the research and ideation part would be a lot shorter, and that we had dedicated more time on building the prototype. However, I realized that the important part here is not the prototype, but the idea itself, and this is what CBI is looking for.

8 This is basically my experience with CBI, I hope it helps future CBI editions, and good luck to everybody!

1 **CBI_17_9**

..Self-efficacy
..Multidisciplinarity

2 Overall, I'm satisfied with my contribution to the team. I have tried to help in all aspects of the project (design, business and engineering).

..Uncertainty management
..Design Thinking
..Energy

3 The first part of the course was the most challenging to me, because I sometimes felt that some of the work in Design Thinking activities wasn't helping us a lot. Nevertheless, I made an effort to embrace it.

..Technical solution/Technolog
..Investigation & Knwoledge d

4 I think that my contribution made a greater impact in the second part of the course, when we needed to start making decisions and thinking about the solution. I did quite a lot of research work, especially in the technical part (blockchain).

..Self-efficacy
..Coordination
..Self-efficacy

5 I'm proud of my role in the final week at CERN, because we had many challenges and I managed to keep calm and work effectively with the rest of the team. I'm very proud of the job the whole team did in those final days.

..Multidisciplinarity

6 Regarding my learning experience, I can definitely say that my most important learnings in CBI have come from interactions with other people.

..Multidisciplinarity

7 The course was a great opportunity to interact with very talented people that had very different backgrounds and life experiences. It was very enlightening to see the thought process of other people, because it made me reflect on my own thought process and ideas.

..Leadership/Initiative
..Leadership/Initiative
..Communication

8 One of the most interesting things I've learned during the course is how to make my voice heard and how to influence team decisions. Sometimes I felt that I knew which were the right steps to follow, but the process of convincing the team to follow that path was challenging.

..Technical solution/Technology
..Energy

9 As for the technical part, I'm happy to have read so much about blockchain, one of the trending technologies nowadays. I'm also satisfied of having learned how to build a basic website and server in a few days. It was challenging to me because I find it hard to learn something new from scratch when I'm under time pressure, but this time I managed to fulfil my goals.

NETWORKING
NETWORKING
..Time management

10 The way I envision the future of this project is being sponsored by one or more global institutions such as UNESCO, UNHCR, CERN, etc. I think it would be almost impossible for our project to succeed without the support a global institution. The project needs to be better defined and take into account many things that we couldn't do in CBI due to time constraints.

11 From a personal perspective, I don't see myself carrying the project further because there are other areas that I find

..Technical solution/Technology

more interesting to work in. But if I continued being involved in the project, I would imagine myself in the technical team, building a secure and robust solution.

NETWORKING

NETWORKING

12 If our team wanted to continue the project, I think we would receive meaningful help from UPC, IED, ESADE and CERN, more specifically from the CERN & Society Foundation. We got very positive feedback from a lot of people so I believe it wouldn't be difficult to find people that want to get involved in the project.

..Technical solution/Technology

13 My expectations were quite close to what ended up happening during the course. Perhaps I expected a little more focus on technical skills, but I've enjoyed it anyway.

..Multidisciplinarity

14 Since the beginning I wanted to be involved in all aspects of the course, not just the technical side, and I'm happy that I was able to do it. From the beginning of CBI to the moment we chose the prototype, I didn't really try to push for any specific direction. I gave my opinion on the group direction but most of the time I was focused on learning new things and observing how our team worked.

..Leadership/Initiative

..Investigation & Knwoledge d

..Self-efficacy

15 Since the moment we chose our final idea, I tried to influence the team so our idea was coherent, feasible and well-defined. I think we managed to define well our assumptions and know where our biggest knowledge gaps were, and I'm happy of how our team developed the idea and the prototype.

1 CBI_17_10

2 My thoughts about this project have evolved along it, both my own role in it as a Margulis team member and as a student of CBI. I think the lack of time is one of the main difficulties all of us have had to deal with during the course, this is probably due to a couple of reasons. The first one is that some of the deliverables or talks, even when some of them were really interesting, were so premature or take too long to really center in the important parts of the process we were doing. I really notice this after the second CERN visit when all the teams were struggling to think in a good enough idea to develop and some deliverables ask for prototypes or business models for our final solution. Second and maybe this is only for the engineers, we are so used to develop fully functional and finished prototypes in all our degree subjects, so have been quite difficult to develop a proof of concept that shows only some of the product features in a short period of time.

..Time management
..Experimentation
..Uncertainty management

3 Apart from this I think that working with people from different disciplines and different opinions has been enriching even though we have had to face some arguments for this reason. There's a couple of things I've learned during this course that have been useful for me team and for myself too, being less critical, thinking out of the box or learning to deal with a lot of uncertainty are some of them. I think my contribution and role in the team have been technical, saying what was feasible and how could be done, helping other to develop further their ideas, proposing some more and solving some problems we had to face to propose a final solution to our challenge. Maybe at the end of the process when the prototype had to being built I isolated a bit from the team final discussions in order to finish something that could represent that we could be able to develop the final solution with enough time to do it. I'm pretty happy with the work done for me and my team during the whole process, in order to learn more about our

..Multidisciplinarity
..Idea generation
..Uncertainty management
..Technical solution/Technology
..Idea generation
..Problem solving
..Problem solving
..Self-efficacy

challenge and how we can break the old system to push science forward.

..Multidisciplinarity
..Self-awareness for professio
NETWORKING
NETWORKING
..Self-awareness for profes

4 I think CBI is a really good idea for the schools to forge relations between them, and more important to the students to being able to work with people with different opinions and cultures, learning a bit more about how their future could be, practicing english, visiting and meeting top researchers at CERN and making contacts and relations with all kind of people that could be useful in the future. There are a lot of things to improve, some of them I've just commented above and some others like the visits to the CERN, because maybe the times were not the ideal ones. Or the schedules because some of us have lost a lot of classes to be able to assist to all meeting, visits and so on. Another one for me are the challenges, maybe too broad in some cases or too narrow in other ones. And finally the team making, at least for designers and engineers because maybe a team required a electrical engineer and another one a graphic designer when they were in other teams that didn't require of their main expertise.

..Uncertainty management
..Multidisciplinarity

5 Even with this things I'm completely sure that this project has a huge potential and is really useful for all of us so I hope more students are able to do it next years.

..Leadership/Initiative

6 I don't discard if it's possible to help in the future another students, guide them through the process or help with some specific points. Or work again with some of my partners in other projects, because we have decided not to continue with the idea we proposed.

7 From my initial expectations on this project to the final outcome have passed almost 4 months of work and dedication and even when I'm a bit disappointed in some aspects I'm grateful to have the opportunity to take part in the CBI and I think that it has helped me to open my mind

and get out of the comfort zone in some aspects.

8 Finally I want to thank you Ramon and Juan, for your work, help and dedication during this course.

1 CBI_18_1

2 In this personal relection, I will be discussing about my own role, contribution and learning experience in the context of teamwork and in my project. I will then talk about the future of this project and finish by comparing my contribution with the initial expectations I had.

..Communication ..Multidisciplinarity ..Self-efficacy

3 I have been part of a team that had little problems in understanding each other. Anyway, it has been challenging to work in such a multidisciplinary team. I am glad of my contribution to the team and I felt like an important member; I hope everyone did.

..Leadership/Initiative ..Energy

4 My importance inside the team has increased as I felt the need to take the lead — not always and not alone. Prejudices made me think MBAs had necessarily to do so, and I think I should have leaded more the team. I cannot help in staying in the second line for the first steps of any project until I make it mine and get fully involved.

..Critical thinking ..Self-efficacy

5 I could have taken a more proactive role at some stages, mainly in the first stages of research, but at the end I gave everything and made a strong and meaningful contribution to the project.

..Energy ..Leadership/Initiative

6 As I just mentioned, at some stages of the research, I felt little motivated, but I guess it is also part of the learning. Most of the days I kept the team together, kept general motivation high and boosted their morale. It was essential as most team members tended to be way too catastrophic after any feedback session. It might have been one of my main contributions to the team, and I am proud of it.

..Self-efficacy

7 Another thing I feel really proud of, and I will come again in the final part of this personal reflexion, is the work I did in the final stages of the project. I would say it is my way of doing things — for good and for bad, I work much better under time pressure.

..Leadership/Initiative ..Multidisciplinarity ..Communication

8 In the last days in CERN, once all the technical part had been done, I fought not to allow the team to change the project two days before the final delivery. I also did not resigning to have a mediocre (non-sense) presentation, and fought once again to tell a story, or at least, to have a coherent structure.

..Multidisciplinarity

9 One of the learnings I need to highlight from this multidisciplinary team working is the following: “The most

..Multidisciplinarity

important thing an engineer can add to a multidisciplinary team is not technical knowledge but a unique way of facing problems.”

..Idea generation

10 Prejudices are most of the times real, but we should somehow overcome them — it is no bad for an engineer to be down to earth but he has to keep in mind his imagination is important too.

..Multidisciplinarity

..Leadership/Initiative

11 My key takeaway of this project is clearly how much a team can improve by incorporating multidisciplinary. But there is something to take into account — in such a big multidisciplinary team I would have a designed leader. If not, decisions are so difficult and slow to take. My point is that a balance must be reached between taking into account everyone’s opinions and taking decisions. It is impossible to reach consensus for every little decision is such a diverse team.

..Self-awareness for professional

12 To be honest, I do not see any future for this project. However, I have the feeling it will impact my future life but in a way I did not foresee.

13 On the one hand, I will not carry on with the project for a number of reason. Firstly, and most importantly, because in this stage of my life I have other plans — I am writing this report from an exchange program in the USA and I am also planning to study a Master’s degree afterwards. Secondly, I do not feel our project has any change of succeeding in the future — if I am not convinced, who will? Lastly, and maybe not that important, non of my teammates are motivated to continue with the project.

14 Anyway, it has never been the primary objective for me to bring this project to life beyond the CBI experience.

..Self-awareness for professional

..Problem solving

..Sustainability

15 Having said that, however, I am sure that this project, and the whole CBI experience will impact in my future in other ways. One of the key takeaways for my future is that the key to success is to encounter problems before they find you. In other words, that not knowing a problem is there does not mean there is no problem at all. It also has raised awareness about SDGs in myself and people close to me.

16 Before comparing my contribution with the initial expectations I had, I will first briefly summarize the expectations I had.

..Uncertainty management
..Leadership/Initiative

17 For me it was a challenging project as in my university we are used to work in groups, but projects are already well defined and engineers tend to see things the same way. I normally assume some kind of leadership, but my main goal has always been to avoid conflict at any cost.

18 In CBI, I expected MBAs to absolutely take lead — prejudices — and as an engineer only bring in technical opinions and not much more (apart from presenting, which I enjoy a lot).

..Leadership/Initiative

19 It took me some time to realize I could also take the lead and in fact, I thing I did it quite well. The part I am most proud of is how I defended our idea 48 hours before final presentation, when some of my teammates wanted to change it from top to bottom. I also took the lead in the final stages of the project when we were short of time and needed to get work done efficiently.

..Uncertainty management

20 Another thing worth mentioning is that I felt much more confident than I expected in coping with uncertainty. There was one day I decided to “trust the process” and this is what I did.

..Experimentation
..Time management

21 We have been a dubitative team. We needed to be 100% sure a decision was the right one before taking it — even when there was no right decision at all. I would have liked very much to be able to have a functional prototype to be able to iterate over and over our solution, test it with real users and improve it. What prevented me to push the project on the direction I hoped for was mainly a lack of time.

22 Overall, I am extremely satisfied with my participation in CBI and the whole experience itself.

1 **CBI_18_2**

..Technical solution/Technology
..Multidisciplinarity

2 My role within Gell-Mann team has been to provide mainly technical knowledge, from both the software and the hardware point of view. Moreover, I have also collaborated with the design aspects, which is a topic that I am also interested in. Unconsciously, I also acquired the role of archiver, along with another member of the team, organizing the drive documentation or documenting the coaching sessions feedbacks, among other tasks.

..Energy

3 With regard to organization and involvement, I consider myself a responsible, committed and hard- working person. Although I combined this subject with the other subjects of the Master's Degree (which involved overlapping many Master's subjects), I have been able to attend all the meetings of the group, except when I had university exams at exactly the same time as CBI subject, which was then impossible. Furthermore, referring to internal group tasks, I have completed the work on time, made alternative arrangements when necessary and willingly accepted my assigned tasks.

..Coordination
..Idea generation
..Communication

4 With regard to teamwork, I have been able to work well with the other members of the group. I have contributed positively to group discussions, providing new ideas and giving my opinion on those of others. Moreover, when things in the project did not persuade me, I did not hesitate to communicate them in order to improve the direction of our project.

..Multidisciplinarity
..Uncertainty management

5 It is very difficult to agree with students who come from such different disciplines. For this reason, our group has gone through many stages: some good (satisfaction, motivation) and others bad such as moments of despair or frustration. But I suppose this is it, and I believe that an always-happy-mood-group can hardly achieve success.

6 Personally, I do not think I will give continuity to this project since currently I have other master projects in mind. Due to a lack of timing, it would not be possible to combine both projects. However, I have enjoyed the project as I have learned many things about a topic that I had never dealt with in depth, such as food waste or the functioning of the food supply chain.

..Self-efficacy
..Energy

7 I am happy with my contribution to the project because, as I mentioned before, I did not hesitate to comment always on both the good and the bad things that were coming out among my group. Moreover, I have been quite active in terms of providing opinions, changing directions, interviewing people, etc.

..Multidisciplinarity

8 On the one hand, I enjoyed working in multidisciplinary groups since I was used to work always just with engineers. Learning the ways of working of other students has been very rewarding. I have enjoyed and learned a lot from it.

..Multidisciplinarity
..Uncertainty management
..Coordination

9 On the other hand, working with people from three different universities has been a difficult task to tackle. First, it has been difficult to coordinate schedules and meeting out of the CBI hours. Second, it has been difficult to agree with some of them at some point, since I consider myself a fairly square-minded person and it was difficult to deal with the most surreal ideas. Finally, I expected a bit more contribution from some members of the team that did not get involved enough. But this always happens in groups of several people, not everyone is willing to contribute in the same way and it is very tiresome to persecute people to work.

1 **CBI_18_3**

..Multidisciplinarity
..Idea generation
..Communication
..Self-efficacy

2 In my opinion, at the beginning I thought that my contribution in this project was going to be just about engineering things. However, as we moved further in the project I saw that I was able to help in other aspects of the work, such as ideation and points of view in the development. I see myself as someone that helped the team to take into account certain areas that maybe they hadn't considered before. In fact, we even had one afternoon where Xavi and I explained Telecom things to the other teammates and it really was a good experience to see others interested in what we are studying and how that could help our team and our project.

..Multidisciplinarity
..Organization
..Leadership/Initiative
..Idea generation

3 In addition, I learned the capabilities of the other teammates outside my area: ESADE and IED. The Esade student helped us a lot with the organization and planning and sometimes he took the role of a leader when was useful. The IED students amazed me with all their capabilities and how they took things and transformed into something new and better.

..Coordination
..Risk-propensity

4 Working as a team was so much fun and I learned valuable things like trust and being able to solve problems when needed. Because we knew we had our backs we were willing to take more risks and go further away from I initially thought. During this semester I learned the importance of constructive feedback.

..Social impact

5 Once the project has been done, I think the idealistic future for LEAF would be to see it in use in real life. I hope that someday, maybe our team or someone else, takes our idea or a similar one and brings it to reality. It would be an honor and it would make me very happy to see that ideas, projects, people and hard work can change somebody’s life.

6 The possible decision of our teammates and I to carry out LEAF would be very attractive and interesting.

..Multidisciplinarity
..Uncertainty management

7 I talked with people that did CBI or something similar and knew somewhat what it was. But is very different to hear about it to actually do it. As I said before everyone helped in more than just their own field and the experience and the way we worked really opened our eyes. In the end and looking back I think we took the best direction without knowing, but when we were making these decisions we were really insecure.

1 **CBI_18_4**

..Leadership/Initiative

2 I see myself inside the OHM's team as the motor that pushes the team ahead with energy, dynamism and fresh ideas.

3 **Structure** and **order** are one of my strong points noticeable behind the composition of the presentations, the posters and the final paper. I couldn't agree more with the allegation:

4 *Making schemes is impossible without a deep understanding*

..Idea generation
..Communication
..Critical thinking

5 In this line, connecting and mixing ideas are daily tools I use to achieve better comprehension on a specific field that can be simplified later. That's why in group dynamics, for example, I'm keen on **selecting the main message** we want to transmit.
I also put in the **critical component of making sense** and I point up the *design part* making some posters in *Indesign* format.
From my point of view, enjoying is the most important. For this reason, editing a video with the happy Ohm team moments was necessary.
(https://www.youtube.com/watch?v=OtA3XsoIzeM)

..Multidisciplinarity
..Investigation & Knwoledge disc
..User awareness
..Idea generation
..Self-efficacy
..Technical solution/Techno

6 Referred to the project, I have contributed actively in the wholly stages we have gone through.
Starting with well-founded research to support the problem definition and making not only the expert interviews but also user interviewees at the same time in order to empathise and go deep into the problem space. Following in the stressful ideation process, *keep it simple* pursuing the innovative *out-of-the-box* thinking has been really challenging. And finally, I couldn't be more proud of the work done by Robert and me at CERN bringing to life the final idea only in two days.

7 Besides the list of specific skills and Key competencies developed in the CBI curricula listed in the CBI Student Guidelines... I would add being able to:

..Uncertainty management

8 · Deal with uncertainty

..Self-awareness for professio
..User awareness

9 · Empathize in specific human needs

10 . Break through the age barrier (we are all equal)

NETWORKING

11 · Connect with people we would never have imagined exchanging

..Self-awareness for professio
NETWORKING

more than one word with them.

12 Despite I’m not really optimistic on the continuity of our project, I can believe in the **sun sensation** idea. And maybe the future has surprises prepared for us. Who knows?

..Idea generation

13 During the ideation process, I came up with the idea called ‘*Elderly people needs to be listened: remuneration for advise’,* developed in the final paper. I can see something there. We will may work on it with Eva Vidal in a next future.

..Idea generation
..Uncertainty management
..Uncertainty management

14 Along with the creative process, it seems that you push, you push and you push without a right direction and a clear objective. It is my first time facing this navigating sensation and the fact of non-controlling the group dynamics has been sometimes a little bit frustrating, but at least, super-formative.

..Self-efficacy

15 At the beginning of the CBI-course, team members ask me what you can contribute to. By this time (September 2018) I didn’t know yet my engineer potential. Now (December 2018), I have it really clear.

1 **CBI_18_5**

..Uncertainty management
..Social impact
..Social impact

2 First of all, I would like to mention that at first I was not sure about our project, and that I thought that focusing on Barcelona was a waste of time because we would not be able to change the world or to solve the real problems related to our SDG. In India there are still millions of people defecating in open air and in Africa millions of children dying because of water scarcity. So, I thought that for my team-mates it was just a project to improve their grades and have something different in their CV. Therefore, I have always been the critical guy that wanted a perfect solution to at least solve the problem we were facing in Barcelona.

..Critical thinking

..Energy
..Investigation & Knwoledge disc

3 HOWEVER, as time was passing by, and we were improving our first system, I saw that all the team was spending as much time as they could. That they cared about the project, and about a solution to the problem. Then, I spent several days learning about the technical part of the filters, and tried to do my best for the team and for the solution.

..Social impact
..Self-efficacy
..Social impact
..Self-efficacy

4 The last month of the project, as people always had a good opinion of our project (which really surprised me), I started to think that maybe it was not that bad. After some prizes came, I thought that maybe it was good. After our final presentation and when we knew we were selected for GSVC, then I knew the project was a little bit successful.

5 I learned from all of them, as they are experienced in completely different subjects. I found interesting what they knew and the way of thinking they had. We had several discussions with different views: business people think “sell it and then (maybe) make it”, and I as an engineer thought “be sure it is possible, try it, and sell it”.

..Multidisciplinarity

6 As a summary, I have learned several skills from my team-mates and from the way of interacting in a multidisciplinary group. I expect to keep learning from this

..Social impact
NETWORKING
..Coordination

7 As we have been selected for the Global Social Venture Competition, we will have to work until March to present our project in Paris. I expect all the team to work together. After we present in Paris we will see what comes next; if we are selected to present our project in Berkeley, or if we win a prize I think we will continue with the project. If not, our journey may end in Paris, which is further than what I (and maybe we) have ever expected.

NETWORKING

8 In the following months, I will be in Switzerland working on my final thesis, and the WaterWall as well. However, I expect to keep in contact with our coaches because I think they have been an important part of the project and they may continue helping us when needed (if they want to, no pressure at all).

NETWORKING

9 Looking further ahead, it is possible that we, CBI students, meet each other again in future projects as we have complementary skills and we

NETWORKING

already know each other.

10 I expected to create a social solution for developing world. I also expected to do the technical part of our project about something that I had studied before.

..Critical thinking

I couldn’t push the project on the direction I hoped because it was a team decision, and I was the only one thinking (or at least expressing it) that way. So I had to adapt to our team direction and to a project that at first I did not feel like mine. At the lowest point I thought this would be just another subject.

..Energy

..Energy

11 However, I changed my expectations as the project was going on, and felt that I was learning and that there was another problem (not so appealing, but a problem) that deserved our efforts. So I put all my efforts on it.

..Social impact

..Sustainability

Finally, we reached a solution for developed countries that was beneficial for the environment. In fact, I felt that CBI was the best subject I did in the University, or at least, the one where I have learnt the most.

1 # CBI_18_6

..Design Thinking
..Multidisciplinarity
..Communication
..Communication
..Critical thinking
..Investigation & Knowle
..Technical solution/Tec

2 Taking part in the CBI course has been a great experience. Since all the projects that I worked on during the degree were specifically technical projects, working in a multidisciplinary team and applying design thinking was such a big challenge. Specially, because of my shy personality and my lack of experience on projects like that, in which you have to share everything that comes to your mind. This is something I have been learning and improving along the project and I think at the end I could finally be able to participate in group discussions. I also contributed with a critical and realistic vision. The main part in which I was able to contribute was the technical one, although none of us knew about water filtering or water quality sensors, we could somehow apply our knowledge in developing the design of this part along with the prototypes.

..Multidisciplinarity
..Self-awareness for profes
..Design Thinking
..Coordination
..Multidisciplinarity
..Communication
..Energy
..Coordination
..Communication

3 In summary, this experience has been very enriching in many aspects. First, the knowledge pills were something very useful, although some of them went too deep into the subject, it was great to learn about the other disciplines since there were things that were useful not just for the project but generally for life. Also, I learned about the design thinking process, which is something I knew nothing about before we started the course, but that finally got to understand. As to the teamwork, it has been also an opportunity to learn about how others work and how they operate within a team. I learned that communication is essential to make things work and that it is important to respect and value all different opinions. I appreciate that we were a very committed team, and that we were very supportive with each other. This also was helpful when facing another big challenge that is public speaking.

..Business sense
..Social impact
..User awareness

4 I personally think that our project has a spot in the market in a near future since problems related to water do not seem to have an end, but they are getting even worse. This is why our project could be actually something useful and needed in our households a few years from now. And not only that, but the product has had a good reception from interviewed potential users and people attending the Final Gala.

..Energy

5 For these reasons I think that it would be interesting to take it further. From what I see, I think all of us are committed with the project and are putting so much effort on it.

..Social impact

6 For the moment, we have to keep working on it because of the Global Social Venture Competition since we were selected as finalists and will have to present our project in front of an expert panel in Paris. After that, and depending on the result of the competition, we would have to consider whether to keep on with the project or not.

NETWORKING

7 Also, since we would be starting from nothing, any help from the

NETWORKING

institutions and the professionals we met could be useful.

..Multidisciplinarity
..Social impact
NETWORKING

8 At the beginning, I knew that the CBI course was an important thing, since we were working on multidisciplinary teams, facing the United Nations Sustainable Development Goals and collaborating with CERN, but did not expect it to go so far.

..Uncertainty management
..Self-efficacy

9 Taking a look back to the start, I was not sure about myself being able to work on a multidisciplinary team and applying design thinking; but as the coaches continuously said, it was important to trust the process. This way, I was able to contribute on the project even if it was not in the way I was used to, since the development of the technical part and the prototype did not come until the last few weeks.

..Self-efficacy
..Problem solving

10 Now that the course has finished, I am glad about the reception that our proposal has had and proud of the work that we have done as a team, since we researched and worked so much to achieve a feasible and useful solution. And as I stated before this is a project I would be willing to keep working on.

1 CBI_18_7

2 After completing the *Challenge Based Innovation* , I can come to the conclusion that this project course served me extremely well. It took me completely out of my comfort zone and that helped me to face new challenges and problems that made me improve in many aspects.

..Coordination
..Energy
..Idea generation
..Idea generation
..Multidisciplinarity

3 I think that the good work atmosphere and commitment of each one of the members of the group have made an excellent result. I believe it has been one of the most important things and has allowed ideas to flow more easily. Moreover, having different backgrounds and being from different nationalities enriched these ideas a lot and we managed to understand each other and make the project go forward.

..Idea generation
..Energy
..User awareness
..Design Thinking

4 In my case, I think I contributed with very good ideas and dedication. The topic of education is one of the least technological. However, it is a topic that interests me a lot and from the beginning, I tried to put aside my engineering side to trust the process, the design thinking, and focus on the problems and concerns about education.

..Investigation & Knwoledge d
..User awareness

5 The research part was the worst for me. I am not used to doing research on these topics at all and more in our case because it was more difficult since we were focusing on Africa. But, I did my best to learn about how to write emails, make good interviews, etc.

..Idea generation
..Technical solution/
..Leadership/Initiativ
..Multidisciplinarity

6 On the other hand, in the solution space, I was able to provide many ideas for solutions, see if they are feasible or not, and I think I have been a kind of hook between the design part and engineering part since I consider myself very creative who likes to look beyond the numbers and specifications.

..Idea generation
..Energy
..Technical solution/Technolog
..Technical solution/Technolog
..Time management

7 Finally, during the last days, I worked a lot doing the prototype. We had a lot of problems, and I had to learn how some components and protocols worked. It was very stressful because of the lack of time but not difficult. I did the best I could with the technical and time limitations we had.

..Problem solving
..Investigation & Knwoledge d
..Communication

8 In general, I have been able to adapt to all situations. I didn't missed any day and I have contributed to solving a lot of problems we faced. I was always organizing and synthesizing all the information we were collecting. However, it has been difficult for me to communicate this information as good as other team members during the presentations.

9 Looking to the future, I do not think our project is going to continue in some way, at least in the short term. It was very challenging, we all learned a lot and became really good friends

..User awareness

NETWORKING

but all of us have different plans. Also, it is difficult since it is for nomadic people in Niger. However, I keep the door open to future cooperation projects about education since, as I said at the beginning, it is a topic that interests me. I made contacts of many interesting people during this project and who knows if we will participate in any project together in the future.

..Technical solution/Technology

NETWORKING

10 To conclude, my initial expectations were that it was going to be a more technological project and we did not have enough time to design and develop our prototype and focus on the technical part. Due to this, I have not been able to provide all my knowledge and skills about it. I also thought that we were going deeper into the technologies and science of CERN.

..Self-awareness for professional

11 Overall, I will not have learned so many specific contents of my degree but the acquired skills, the challenges I had to face and the different people I met make this project a unique and very fruitful experience that I will remember for years.

1 **CBI_18_8**

..Technical solution/Technolog
..Multidisciplinarity
..Multidisciplinarity
..Self-awareness for profes

2 There is a lot of knowledge acquired by engineering students through the entire bachelor and master's. However, not many projects involving multi-disciplinary teams are offered. CBI lets students foresee how their future in the non-academic world may be (where usually different- background people will be working by their side).

..Technical solution/Technolog
..Technical solution/Technolog
..Communication
..Investigation & Knwoledg

3 Also, there is never enough with the technical aspects. My project has made me learn the basics about biomedical-oriented IoT as well as the always-needed research and public-speaking capabilities.

..Multidisciplinarity
..Leadership/Initiative

4 I would define my role as an intermediate between the technical and the other (business, design, leadership) aspects. As I would define myself, I am more of a managerial position within technical fields.

..Multidisciplinarity

5 As stated before, since my role is not purely technical, my contribution has been equalized through the project, helping in the innovation processes, reviewing the design contents, working on the business and, of course, taking care of the technical aspects.

..Sustainability
..Entrepeneurship

6 All the projects result of this year's CBI are interesting. The fact that they are oriented towards a more sustainable world gives them even more hype. That, and the fact that I am a passionate of the entrepreneurial world, would made me glad to be part of the continuation of any of the projects (of course, including mine).

..Business sense
..User awareness

7 As stated, it would be wonderful to continue with any of the projects, and even more with mine. However, it's true that I would like real feedback regarding on the continuity of the projects. It's nice to know that you have work well and performed a good project, but for this to get out to the real world, real feedback should be given to those groups whose projects are candidates to be successful.

..Uncertainty management
..Uncertainty management

8 The initial expectations were kind of accurate. I worked last year in another project —in the I2P subject— and the workflow was similar. Engineers, and their straight-forward minds, tend to have difficulties when dealing with innovation processes. This project has helped my innovation capabilities, as well as strengthen my patience (which always tries to find a good solution too early).

9 What prevented (or not) my decisions to go through was democracy (within my group), which is always fair. Everybody has their own vision of the project —which sometimes do not meet— and trying to follow all at once can result in catastrophe.

1 # CBI_18_9

..Problem solving
..Multidisciplinarity

2 The CBI project was an exciting trip through collaboration, learning to work within a multidisciplinary team, and organise every piece of the puzzle to get an innovative solution. Throughout this path, different individuals of the team had different roles, whether we liked it or not.

..Energy
..Uncertainty management

3 Talking about Ohm's team, when we first met each other I thought I had been lucky: every one seemed hard working and motivated to create something new, we just had to let the process begin and see how each of us fitted in the group. Personally, I am the kind of person that prefers to have everything prepared in advance, rehearse everything multiple times and recheck our work to minimize mistakes.

..Organization
..Leadership/Initiative
..Communication

4 After some days, we had the first deliverable. There was a lack of organization and let's say that maybe we didn't make clear everybody's job, so a day before there were still several tasks to do and no one seemed to feel responsible for that. So, I felt like I had to do it, for the sake of the team. This was just the beginning and maybe it was just a small communication breakdown , I thought... It was not. That first week was a prelude of what happened during the whole course in our team.

..Multidisciplinarity
..Organization

5 I believe that in a multidisciplinary team like these ones there is an added handicap, and in order to overcome that gap all the teammates should work hard. When that doesn't happen, some team members carry a higher workload than the average, which is harmful for everyone in the team and the project: it makes the team weak and leads to deliver last minute and with worse results.

..Uncertainty management

6 My feeling during this process was of lagging behind all the time, which stressed me more than it should have. I talked about it several times with different coaches (i.e. Ian and Ramon) and they were very helpful, but of course it was an internal problem that only we could solve.

..Energy
..Organization
..Leadership/Initiative
..Energy

7 At a more advanced stage, the lack of commitment, work and organization was crystal clear in some team members, and talking about it through feedback didn't seem to work. I felt like the group was lacking of a leader and no one seemed to care, so without pretending it I was that figure for many weeks. When direct and immediate tasks were assigned to the other team members, they completed them successfully, but only by that way. I felt lack of initiative in the others, which frustrated me at some points.

..Multidisciplinarity
..Uncertainty management

8 After a while, I reached the conclusion that we are all in different stages of our lives, we have different priorities and ways to think and work. Maybe the team members that were not so excited were really good at their own jobs or expertise areas, but they didn't know how to fit in a multidisciplinary and *out of the comfort zone* project like this, which is obviously hard. For example, some team members proposed

a 3rd checkpoint presentation scheme full of numbers and tables of risk and cost calculations, which was totally out of context but was obviously a hard work.

..Energy
..Energy

9 But after a while, some members told me some words that made me feel like the opposite: they just didn't feel like committing so much. And that's when I thought that, for the sake of the project, those of us within the group willing to work hard had to push it forward.

..Leadership/Initiative

10 Of course, I have to say that we all make mistakes and I am the first one: when I felt that the group lacked a leader maybe I should have tried to manage the team members better, or find better ways to motivate them, or I don't know.

..Coordination

11 Personally, this whole experience made me learn a lot about group and people managing, but it could have been less stressful and more fruitful if my teammates were as eager as I was.

..Investigation & Knwoledge disc

12 Our project is indeed a long-term project that needs tons of research and technological advances before it can be developed.

..Problem solving

13 The idea that we suggested was demonstrated in a controlled environment in the exposition at IdeaSquare the day of the final presentation, and given that we knew all the variables of the space we could make a functional prototype that showed the operating principles.

..Experimentation
..Technical solution/Technolog
..Business sense

14 It has to be mentioned, though, that before a project like that can reach any market or work in a real (and random) environment, like a whole house, a lot of progress should be done, especially in fields like Image recognition and AI, infrared high emissivity and low thermal mass materials. To do so, tons of private investment are required, and we just had the idea.

15 Of course, as a team member of Ohm, I would love to see this project implemented at its full potential some day, but I am totally conscious about the difficulties it faces.

..Technical solution/Technology

16 Given my Telecom engineering background, I landed at this project with the expectations of carrying out a work that had a high engineering component.

..Technical solution/Technolog
NETWORKING

17 At the beginning I thought that my work at CBI would be much more advanced in the tech aspect than it has been, given that an organization like CERN is behind it.

..Design Thinking
..Multidisciplinarity
..Experimentation

18 After some weeks I realized the importance of the design thinking in projects like this one, so I tried to adapt myself into this project, working in other fields like ideation, design, creativity, business, innovation and others. Besides, I believe it strongly depends on the prototyping being carried out by every team, and I believe that that freedom makes the project better.

..Self-awareness for professional

19 This, in my opinion, was a drawback at the beginning, but then I realized that these are the kind of areas that we would not learn at the technical university, so I was satisfied with it.

20 Overall, the whole experience met my expectations in one way or another.

1 **CBI_18_10**

..Uncertainty management

2 During all the process of the course, I have had many different feelings and opinions about the project. As an engineer, I am not used to working this way and in such a broad topic as gender equality is, so I have had many weeks in which I thought that our team was not going to achieve a final idea or product. However, after the last visit to CERN and after finishing all the presentations and dossier about the project (and after arriving to a final idea), I have realized about everything that I have learned and the value of this program.

..Idea generation
..Energy
..Technical solution/Technology
..Design Thinking

3 In my opinion, my role in the team has been equally important compared to other team members. During all the process of finding a problem and a solution, we have been ideating and brainstorming together, so I think that all the members had the same amount of work and relevance in the team. At the end of the project, each of us worked in his/her respective field, so I was comfortable in working with the prototype with Guillem. However, I believe that I have learnt the most in the stages when there was no technical part, since, in engineering, I had never gone through a design thinking process.

..Multidisciplinarity
..Design Thinking
..Self-awareness for professional

4 I have learned about working in real multidisciplinary teams and how to understand other ways of working that can have people from other fields. Every member of the team had a different background and very different knowledge and, when we met at the beginning, it was a little bit complicated to start working because we had very different ways of coping with it. I have also learnt about concepts that I knew very little before, such as design thinking, innovation or prototyping. I think that most of the knowledge pills were interesting and useful for our project, but even more for our professional future.

..Multidisciplinarity

5 Lastly, I have also learnt about the studies at IED and ESADE. I have to admit that (specially in the case of IED) I knew very little about what they studied and what they were capable of doing after their studies. After doing a project together, I value more their capacities and their role in the team, because it would have been impossible without them.

..Entrepeneurship
..Energy

6 The team has been very passionate about the idea during the last visit at CERN and some members mentioned the idea of creating a start-up, since we thought that the idea was valuable enough to make it real. Also, the good feedback received from different professors of the teaching staff helped us a lot to be more motivated during the last intense week and also to make us think in possible future developments.

NETWORKING

7 If we finally decide to make this idea real, we would like to

NETWORKING

receive advice from the three schools, since the guidance through all the course by all the teaching staff has been very positive and has helped us a lot. The weekly coaching sessions were very relevant to know exactly where we were in terms of the design thinking process and made the path clearer for us.

..Multidisciplinarity
..Self-awareness for profes
..Entrepeneurship

8 In conclusion, after this project, I am more available to work in a really multidisciplinary team with people from other fields a part from engineering. For example, I had never thought about creating a start-up and I envisioned my future working in research, but now I am wondering what to do in my future, since this project has been completely worth and the learning outcomes have been very useful.

NETWORKING

9 To be honest, I do not remember my initial expectations of the entire course, but I think that I decided to apply for the CBI@CERN because it offered the opportunity to visit one of the most prestigious research centres in the world, so I thought that, in an engineering point of view, it was a very good opportunity to progress in my career.

..Uncertainty management

10 The truth is that in the second week at Sant Cugat I discovered that the project was very different and it tackled the initial steps of a project where you had to find the problem and the solution. A lot of these steps were complicated for me, since in technical fields we are not used to work like this, so I had moments in which I enjoyed the classes (when we were near a solution) and moments where I was very unmotivated (when we were very lost)

..Uncertainty management
..User awareness

11 Now that I have finished the course, I have understood that all these feelings appear because we have done a very broad project that tackled lots of problems and we have focused it for real users. I think that the learning outcomes have been huge and it has been a great experience.

NETWORKING

12 Last, but not least important: I have met amazing new people that have improved me as a person by teaching me from lots of different fields and by understanding other ways of working. It has been an amazing experience.

1 PDP_15-16_Fall_1

2 In this document we have made a study of the different methods proposed to find out the displacement between two images taken from a coherent light with a speckle pattern. In the first sections we have made a theoretical study and at the end (in the section "Example") we have implemented a particular case with two images.

..Self-efficacy
..Technical solution/Technolog
..Critical thinking

3 We have proven that, as shown in theory, 1D DFT is the fastest method, while the cross-correlation is the slowest. Despite this, we cannot ensure that 1D DFT is the best, as it can only detect horizontally or vertically displacement (and it must be previously introduced to the system). At first instance this does not seem to be a problem because we know that a printer only moves the sheet of paper in one direction (vertically), but it is possible that some kind of horizontal displacement could be occur because of deformations produced by the ink.

..Technical solution/Technology

4 The second fastest, 2D DFT, can compute both axis of displacement. The main problem is that the algorithm used to find the location of the peaks is more complex. In addition, these two methods can only compute displacement in forward direction. They cannot detect if the direction has been in positive way or negative way because they work in the frequencies domain. Moreover the displacement has to be inferior to half size of the image. If this condition is not met, we will get erroneous results as the frequency domain is symmetrical every 0.5Hz.

..Technical solution/Technology

5 The "Correlation from DFT" method is interesting. Mathematically it is the same as normalized cross-correlation, but faster. It is not as fast as those described above but it seems to be the one with the best time/veracity ratio. Its peak detection system is one of the simplest. Moreover, as we have tested (section "Comparison") it has the best hit-rate, is able to compute large distances and smaller ones also (even those lower than speckle dot size) which is very important in the stage 3.

..Technical solution/Technology

6 The "Phase Correlation" method has the particularity that it works very well if the image has suffered only a displacement, but (for example in the stage 3) speckle pattern also changes (it is appreciated more by moving long distances) and this effect causes erroneous detections. Even though its peak detection system is one of the simplest. Due to filtering, the result is very clean, with a well-defined spectrum (only there is a peak whose location is the displacement).

..Technical solution/Technology

7 The slowest method, 2D cross-correlation (normalized), is the most robust. It always works fine but it is very slow in comparison to the others. The peak detection system is also very simple. We will use it only in those circumstances where other methods are unable to detect displacement.

..Technical solution/Technology

8 One thing to note is that the sensor of the camera must be aligned as much as possible with the axes of the substrate. If this is not met, a displacement of a single axis of the substrate won't be a displacement of a single axis of the pixels of the sensor, thereby obtaining measurement errors.

..Technical solution/Technology

9 For now (at stage 3) the "Correlation from DFT" method seems to be

the best. We also have to try some additional improvements as subpixel detection (by using interpolation) or mathematical morphology.

1 **PDP_15-16_Spring_1**

..Technical solution/Technology

2 Each team has found some interesting things in their respective fields. In the data modelling part we found out that, as explained before, there was a deviation in the measures value due to the way we carried out the measure, squatting instead of lying on a horizontal position and despite of that we also realized that this deviation was corrected thanks to the impedance the dry electrodes added to the system.

..Organization
..Coordination
..Business sense

3 This project has also been very useful for us because one of our main goals was to improve our knowledge of Android programming. We have been working in parallel, so we have also enhanced our teamwork. This project has showed us other perspectives of the business and developer world.

..Self-efficacy
..Problem solving
..Self-efficacy
..Critical thinking

4 From electronics group, we are very satisfied with the work we have done during this months. We achieve our objective to measure bioimpedance with 4-wire system changing the initial structure of AD5933. Once the complete system worked properly, we were able to programme the chip with Arduino to fit our part in the complete project. Overall, we have seen that we have the knowledge to do many things, but we do not have enough practice as to make them in the most optimal way.

..Organization

5 So for us, it was highly important the organisation, the distribution of works and the understanding of what we were doing in every moment.

..Technical solution/Technology

6 If we look at the communication part, we can realize that it is much easier to work with modules bluetooth as the BLE112, in which is already firmware installed and do not have to program them from scratch, as in the case of our first choice (B1010SP0 CSR). Furthermore, we noticed that the programming of a microprocessor is not simple, so we have used Arduino to control everything. It is better to work with environments that we know or can access information easily to work with them. Even so, we are satisfied with the work done, because communication has been established successfully.

..Business sense

7 In the business part we have found out something quite interesting, probably the reason of this project, and it is that it could be economically profitable, we could make money from it thanks to relatively low costs and the average high price our market niche has. So our efforts could be monetized somehow, or at least it could be tried.

..Technical solution/Technology

8 We have also realized that the bioimpedance technology is a pretty good tool to track health parameters, giving

..Technical solution/Technology

accurate measures if they are carried out in the expected positions, but it has a major downside, it has to be always under the same conditions, and never while practicing sport because otherwise, it has a lot of variability.

..Self-efficacy

..Self-efficacy

9 The more personal part has also been important and this project has wide-opened our eyes, giving us a much broader perspective of our field of study, and has shown us that, although we could think we were not able to do some things, we have acquired skills that have allowed us to face big problems and solve them step by step and in little and easier pieces.

..Time management

..Time management

..Uncertainty management

..Time management

10 We want first of all to start making a little bit of self-criticism, especially of our project planning skills. We have not usually been able to fulfill the requires tasks in the expected time, although we started with a good pace, the first problems we had, meant big delays due to lack of solutions to them and after them everything was a battle against the clock to complete the project. The problem was not only the lack of solutions but the execution timing of them, which was neither the optimal one nor a good one. This was our major weakness in this large project, so it meant big delays due to the size of this project.

..Planning

11 Despite of that, and having been very critical in this aspect with ourselves, everything worked well at the end so it has not been as critical as it could have been, but it is something we should improve for future projects. We should take into account the importance of a good planning and, especially, to save time for delays and the “put-all-together” phase, which usually is taken for granted, thinking that if everything works separately it will work together, but this is never true.

..Coordination

..Coordination

12 The overall performance of the team has been good, again taking into account that we have reached the expected objectives we set at the very beginning of the project, and we have been outstanding in the tasks reassignment, everybody often accepting which was the best for the team, and supporting others with their tasks. We have also been outstanding in the interpretations of the other teams needs, i.e. if someone had a vision of how our product could be implemented, or some new features that could be added, everyone thought how could, his/her team, help in that new idea and how could that be developed.

..Uncertainty management

13 To end this section, and the whole document, we would want to have a special mention to the things organizers and lecturers have been doing during the whole project. First of all congratulate the organizers, coordinators and lecturers of the subject for their work in such an interesting subject. Despite of that, we think that there are few things

..Uncertainty management
..Uncertainty management
..Uncertainty management

that could be improved. The first of them is the excessive freedom we are given. Although we know is a training to what we will find in real life, we found ourselves fighting against a lion with a chair and whip, almost naked face-to-face to quite a big project and, taking into account we had never done anything similar before (we do not think PBE or ENTIC are a good preparation for what this project requires), this has been very hard for us.

..Planning
..Organization

14 In second and last place there should be also a more important part in project management, which has proven itself to be the cornerstone of everything, and has been only given a quick look, and it could be an area of interest to some team members, more than the most technical part.

15 Despite the bad things, the overall project has been quite interesting, and all the people involved in the project, lecturers and organizers, have been keen to help with the whole project in general.

1 **PDP_15-16_Spring_2**

2 Once completed all tasks and parts of the project, we present the conclusions which we reached on the product.

3 Synthesis of the methodology used:

..Investigation & Knwoledge disc
..Organization

4 First of all we started doing a little market research to analyze what kind of product What could we make, to meet the specifications. We designate different points of research to project members what led us to be more efficient in realizing that we could introduce new product on the market.

..Organization

5 Once we have defined product, we divided up the tasks into smaller groups which have developed some of the product, with small control points have been analyzing and collecting functional parts to not delay the project at points where they had dependence on parts of another subgroup.

6 Aspects to emphasize:

..Organization
..Time management

7 One of the great benefits of this method is that we managed to cover a lot of information and progress faster than if we had focused all on the same point of development.
With this we have optimized time and resources within in the development.

8 The technical details:

9 Data acquisition:

..Organization
..Energy
..Problem solving

10 We have worked with other budgets that calculate the same as our pad, and it helped us to make a clearer idea of what we wanted. Sometimes it seemed like we did not know to where we should go, but we have learned to not forget the objectives and search the way to do the measurements correctly and, which is also very important, to contrast the results we were getting every time. It was very interesting to learn how to acquire these kind of data and how we can get the parameters of body composition, heart rate and respiratory rate from it, also the relation between the continuous signal of the skin and the fatigue.

11 AFE and Microprocessor:

..Technical solution/Technology

12 Due to the programming of the AFE4300 we have strengthened the base which we already knew of the use of registers of a microchip in order to configure it the way we want it to work. At the same time we have learned to establish a communication between the microprocessor and the chip, so this means we have learned how to use it one as a master and the other as a slave, this made us learn how the SPI protocol used for these communications works.

..Technical solution/Technolog
..Critical thinking

13 The microprocessor code works but is not optimized to achieve the best performance, this is a task that could be improved if we had a little more time.

14 Android application:

..Technical solution/Technology

15 With the use of android studio we have been able to learn and specialize in native android programming, and management of libraries for the graphic look for strong and funny interface. In addition to methods for using functions in the background, so that we could make Bluetooth connection.

..Self-efficacy
..User awareness
..Self-efficacy

16 Our objective in this project:
The first and the most important in this project is that we could create a new product, and put in the market a new idea that is one of the most difficult things now a days.
Our main objective in this project was to create an innovative new product that can increase labor productivity at work, while we could help people control their vital signs. So being finished product that meets and observe what we wanted, we can conclude that we have accomplished our goal

17 Below are detailed some points that could have been improved as well as the points that we believe are well organized.

18 **What to improve and what to keep?**

19 From the beginning it has been clear the whole set of documents as deliveries to each other has been a bit confusing, but we believe that everything is pretty well organized.

..Organization
..Communication

20 We think that maybe some of the meetings would not have been necessary because between us there has been good communication and the teachers have been quite involved in the laboratory work.

..Self-efficacy

21 Overall we are very satisfied with the project we have done and the way the course is organized by the teachers.

..Organization

22 It could have been better organized by our team the distribution of work and meeting deadlines regarding the documentation that must be delivered throughout the project.

23 **Performance as a team**

..Organization
..Coordination

24 In general, the team has worked together with a good distribution of the tasks that each member of the team has to perform, with a good work atmosphere and coordination among the different work subgroups.

1 **PDP_16-17_Fall_1**

NETWORKING
..Business sense

2 One of our main objectives during this project was to offer a smaller tag for marine animals. The reason why we needed to achieve that is because our client would like to study other types of fishes, maybe smaller than tunas. In addition, there are some other companies in the market that already offer tags and we wanted to make a difference with the size and the weight.

..Business sense
NETWORKING
..Business sense
..User awareness

3 Taking into account that our client is an ONG and that their members are working in order to protect and preserve the natural environment, they do not have much economical resources. Moreover, the competition in this market offers very expensive tags. This is just another complication for our biologists and fishers to study tuna habits in order to protect the species, and this is why we tried hard to find the cheapest way to make our tags.

..Problem solving
..Energy

4 We looked for the smallest and cheapest electronic components, in proportion. Also, we looked for a battery that offers the power that we need without costing us a fortune. We found a way to make pressure studies in a very cheap way, as well as researching to find the low cost mechanical materials that we need. With all this commitment with minimizing the final price for our product, we worked very hard to achieve it, in order to offer a better and a cheapest way to our clients, who work with minimums with the goal of protecting marine species.

..Problem solving
..Technical solution/Technolog
..Business sense

5 Having a look at other tags in the market with a similar price to our product's, we realize that ours is also able to obtain pressure and magnetic values. The magnetism sensor allows us to get a more precise location of the tag and the pressure sensor to determine the depth. This is an important point because the tags in the market that are able to capture magnetism and pressure values are way more expensive than ours.

..Technical solution/Technology

6 Additionally, we have been able to find all the components of digital type. This has allowed us to obtain a final product with very simplified electronics that make us expect a higher reliability compared to other tags in the market. We can make this statement because we were able to study one of the tags of another company and we realized our tag was way simpler in addition to covering a wider range of functionalities.

..Coordination
..Uncertainty management
..Leadership/Initiative
..User awareness

7 Analyzing how the lectures and different classes have been carried out, we think that overall this subject has been very useful for us, because we have learned to work in a large group and to solve problems in a different way of what we have done until now. This project was not a guided one, we have faced a complete challenge, building an engineering project starting from scratch, just on the basis of our customer needs, having to develop a whole design proposal to satisfy these needs.

..Uncertainty management
..Communication

8 In our opinion, the fact of having 3 different teachers whom we could have as a reference is useful, but we have noticed that through the course not all of them were available all the time, which has made some of our tasks more difficult. On the other hand, when it came to moving forward in the project and rehearsing for the final presentation, they have been very useful and helped us a lot in this aspect.

..Coordination

..Time management

9

About the teamwork and things we could have done better, we think that we have worked well as a group, helping others when they needed it and supporting each other. Overall we have carried out the project and achieved our goals, but as mentioned several times along this document, the lack of time has been the most limiting factor during the course, and the main reason why we have not fully finished it as a definitive prototype.

1 **PDP_16-17_Spring_1**

..Organization
..Time management

2 Along the different project development phases, even in the earliest states, Strato3 team has acquired some thoughts that proved to be key points. Most of those lines respond to organization issues, in a wide sense. Since one of the constraints is, as always, time, the next points arise as a priority.

..Investigation & Knwoledge d
..Time management
..Time management
..Critical thinking
..Organization

3 Following a chronological timeline, what should be noted first is that it's strictly relevant to mark and define concrete goals to achieve. A lot of time on the beginning was invested researching, gathering information and getting some knowledge basis to start to work with. However, lacking a straight vision with delimited objectives to solve in a short term ended up in a waste of time. Such matter could happen if your development tools have tons of features and functionalities (or even if there are more than just one way to face a problem): learning properly how to get profit of those devices in a complete wide sense requires a huge amount of time and, after all, most of times it's simply not needed. So, in order to not get lost, it's a high priority task to be very very accurate proposing lines of research.

..Investigation & Knwoledge d
..Time management
..Investigation & Knwoledge disc

4 Related to this point above, the team has learned to never underestimate previous work or the primary sources of information. Again, time could have been saved having a deep knowledge of these sources, because problems and issues were already reported and solved. While it seems a bit of a waste on the beginning, it's crucial afterwards. Knowledge management is considered as one of the primary goals and so it's pretended to be reflected on this whole document.

..Coordination
..Coordination
..Organization

5 Team members also count as one of the highlights within time constraints. Strato3 members realized how relevant is to know each one strengths and weaknesses, make a fluent cooperation and establishing a dynamic task assignment. Sometimes, those lines were relaxed and some extra work paid the price.

..Experimentation
..Problem solving
..Time management
..Experimentation
..Experimentation

6 More technically oriented but not least important, testing comes as a milestone. No matter how well something it's been thought or designed, problems and issues will arise when coming down to hardware implementation. Sometimes, it's hard to prevent or estimate how to solve them. For this matter, previous testing plays a huge role managing limited resources such as, not enough mentioned, time. Testing shines as one of the key points in the whole project development.

7 Reflection document

8 This section of the document pretends to give a critical yet reasonable view of some guidelines followed or given by lecturers, the team and its performance.

..Uncertainty management
..Uncertainty management
..Uncertainty management

9 About lecturers, it was felt that deliverable documents often lacked a more accurate description: some sections were indeed confusing. Problems proliferated when speaking of CDR (Critical Design Review), since there was no template and it was quite difficult to know what information and how should have been it written. Also, being the first time the project involves an external entity, some organization between UPC and ESADE were

..Uncertainty management

missing, leading to misunderstandings when it comes to deadlines and again, documents.

..Idea generation
..Time management

10 Aside from this, the project ideas and guidelines were really good, but the time left to reach the goals was quite short and sometimes it seems that the credit charge needs to be thought again accordingly, because it has to live and collides with other subjects: the project goals and work is really time hungry.

..Time management
..Organization
..Communication
..Communication
..Business sense
..Problem solving
..Organization

11 The team's weakness during the project was organization. ESADE students and UPC students failed when managing to coordinate and share knowledge at its full commitment. That left open some points regarding knowledge management and therefore guidelines between business idea and a product service conception development, which messed up with a more straight technical implementation solution. Inside UPC students, tasks could have been assigned on a more homogeneous way among the team members.

..Coordination
..Problem solving

12 However, and despite this, the team managed to work together and, yet a messy start, final results proved to fix this matter in some way, although it could have been done better.

1 **PDP_17-18_Fall_1**

2 Once this project is wrapped up, we feel it’s important to take a look back at what things we have achieved during the process of this work and what things we have learned in different engineering aspects. Not only that, but also it’s important to make a self criticism of our work as a team.

..Coordination

3 We came from a point in which all of us had no idea about anything of this project. Not even the programming languages (C++ or Yaml) are studied at the University, only a simpler language (“C”). Apart from that, none of us were experts in the concepts of spacecrafts and its functionalities, parts of it, etc. The orbit of a satellite, the attitude, the payload, the energy and data flow, were just some of the many things we also needed to learn in order to fully understand how a satellite works. In fact, the complexity in it is so big the simulation of the models we came up with it isn’t even close to the real models of a satellite. To finish, although all of have worked in small projects and have already been involved in some team-up work, this was clearly a step forward in this field for all of us.

..Uncertainty management
..Technical solution/Technolog
..Uncertainty management
..Investigation & Knwoledge d
..Problem solving
..Coordination

4 We have never really worked in a project that big, maybe it was too big as we couldn’t finish it all.

5 Time was really an issue in this project. At the beginning of the project, we spent a lot of time advancing in a really slow mode, although it is perfectly normal, as we didn’t really know how things worked (GitHub facilities above all). That took away almost 2 months of work that could have been really valuable by the end of the project. The fact that all of us had examination tests at the University also slowed the advance of the project severely and took away a lot of our time as well.

..Time management
..Time management
..Uncertainty management
..Time management

6 Overall, we came to the conclusion that this project isn’t something easy to do in a month or two, and, despite all the hard work of all of us, we didn’t reach the final objective. Factors like time and complexity were crucial during the project, but that didn't stop us from trying. We came really close to finish it, in fact, although the models implemented weren’t as real as they should have been, a complete integration of the project would have been viable in a month or so.

..Critical thinking
..Energy
..Critical thinking
..Self-efficacy

7 The members of the DSS team are really proud of the results achieved, giving that the progress made since the beginning is huge and impressive. All of us have learned at least one programming language, have acquired a lot of knowledge of spacecrafts and its modules, and also the functionalities of the Model-View-Controller structure of the project, a very common skeleton project that we will definitely encounter in the many projects we may participate in the future.

..Self-efficacy
..Self-awareness for professional

8 As one of the teachers in charge of thisproject once said: “Focus on progress, not in results”. Maybe that’s the key to determine whether this project has been really successful or not.

..Self-efficacy

1 **PDP_17-18_Fall_2**

..Problem solving
..Experimentation
..User awareness
..Investigation & Knwoledge d

2 This report introduced an investigation project concerning the recognition of information in handwritten documents. It presented the scheme designed by the team capable of carrying out the desired task, along with the tests applied to each step of the system, not before establishing the necessities to satisfy and researching which the best technology to work with was.

..Critical thinking

3 At this point, it can be concluded that the performance of some blocks of the system is better than others', thus, allowing the implementation of the first but not the second ones.

..Planning
..Technical solution/Technolog

4 The most challenging objective was locating the bottlenecks of the design. In order to face this goal, each block of the system was tested and the results analysed, merging in stating that the segmentation into characters and the recognition of handwritten words are the blocks that the current technology does not allow implementing with enough good performance yet.

5 As presented in section 6, System Characterization, the results of the segmentation are not reliable enough to allow implementing this step of the design with success, depending too greatly on the resolution of the picture and the calligraphy. This provokes that the following blocks carry the errors produced and therefore their performances will be affected negatively. Because of this, some algorithms in both the Recognition and Decision blocks cannot be implemented, as they require a good previous segmentation.

6 The second bottleneck is found in the Character Recognition block. The extraction of characteristics is not standard. Several approaches were tested, achieving not enough good results. Furthermore, configuring the neural network is also an open step to design with a great number of possibilities and, the most important factor, the database of sample handwritten characters used had too few samples of each letter, causing the neural network to present very unreliable results.

..Self-efficacy
..Problem solving
..Social impact

7 Considering the above statements, it can be concluded that the investigation project was successful. Testing each block of the design and analysing the results allowed to affirm with conviction and precision the point until which the current technology would work in the system proposed by MSF.

..Coordination
..Organization
..Planning

8 Facing a project with a team of people who do not know each other might sometimes not be an easy task. This is why it is necessary to organize the project from the

..Organization ..Planning

beginning and define the role of each component.

..Organization ..Communication ..Coordination ..Coordination

9 As presented, this project is divided in main and secondary blocks. Therefore, the team was divided in groups of two or three people, depending on the complexity of each task, and the work was divided so that a different block was assigned to each sub team. This has resulted to be a good procedure of work as it was possible to work in different blocks at the same time, which was the most efficient way to work on this project. On the other hand, each group was specialising on one block of the system designed, and punctually this has caused confusion in understanding how the blocks of the other groups work. A way of solving this problem is to assign tasks from different blocks to each group, so that every component of the team understands completely how the system is being implemented. Another positive aspect to mention about the performance of the team is that the meetings were set so that each person could propose his or her opinion about how things should be done, allowing having multiple options for each block and selecting the best one amongst them.

..Problem solving

10 Concerning the conditions of the environment of work, it has to be mentioned that the tests were applied to prepared documents, not to real medical registers, as Médecins Sans Frontières was not able to provide such documents due to the difficulty of acquiring them.

11 From the point of view that the team was formed by students, it is desired to highlight the collaboration from the professors, guiding and helping in different aspects throughout the project.

1 **PDP_17-18_Fall_3**

2 In this section, an analysis of the different aspects to improve and its possible solutions is done. Possibly more improvements could be done, but these ones are the most remarkable.

3 Bad photos (too many pigs in a picture, bad position...) are stored in the system and the associated measurements are not correct, so they are unnecessary. In addition, approximately 500 photos are taken per day: if the 90% of them were deleted, there would be still enough to extract interesting data. Moreover, another ultrasonic sensor could be installed to detect the rear of the pig, and, then, ensure that it is in the correct position by detecting it by the two sensors at the same time. A software photo altering algorithm could be developed as well, in order to decide which photos are valid to be processed by image processing algorithm and which are not.

4 The contour detection algorithm works well, but sometimes it does not work properly.

5 To improve it, a more exhaustive training of the _tting model has to be performed.

6 The marking system shoots little paint, which is sufficient, but it could be better.

..Technical solution/Technolog

..Problem solving

7 Therefore, a bottle with a bigger dispenser should be searched.

8 Although the system is planned to work with multiple others running at the same time, the tests have not been done, so it could be interesting to study how many of them can work in parallel, mainly by the connections.

9 Now the data analysis is very limited, it only consists in a graph with the weights classified in ranges of 5 kg. Once a database as extensive as this one is created, the possibilities of data processing are many, so some of the possible extensions that could be made are:

10 - Tracking the weights to detect if a pig stops eating, and a system of alarms and
11 - notifications.
12 - Prediction of the next stage of marking, for an optimal weight.
13 - Growth statistics for different races.

..Self-efficacy

14 Although there are lots of possible improvements, the product is what was expected to achieve, so it is considered that the requirements have been achieved.

15 Here it is going to be described how the relation with the professors and clients has been, and also how the team has been organized.

16 The relation with the professors has been good but, at the same time very different with each one. Ramon have had a more

flexible way to work with us, he has been helping the image processing team but, at the beginning, he let them investigate different possibilities on their own, possibly even knowing that they were not the best solutions, but they learned a lot thanks to this. Miguel has been helping the team developing the marking system, where he has been really necessary, because no one in the group had previous knowledge about mechanics, so he has set the pace of what was going to be developed.

..Communication
NETWORKING

17 The experience with the clients has been also excellent, the communication via e-mail has been fluid and three visits have been done. They have always been receptive and have helped the development of the project with everything they could: weighting pigs, marking them, taking pictures... and generating real data to contrast our results.

..Coordination
..Organization
..Time management

18 The team members did not know at each other at the beginning of the project but, finally we became great team partners. However, the roles and tasks were assigned the first weeks, the fact that we did not know each other and the lack of experience caused that those weeks were not very efficient. At the beginning, a time plan was done, but it has been difficult to follow it, because we did not know exactly the way of working of the others and what supposed those tasks.

..Communication

19 The main communication of the team has been in the PAE classes, but a constant communication via WhatsApp of the management team has been very important to organize the tasks every week.

1 **PDP_17-18_Fall_4**

..User awareness

NETWORKING

2 Foot analytics had a system that collected data through the Wi-Fi, and then processed it into customer-behaviour information. They were using only the Wi-Fi packets with static MACs and they proposed us to improve their system, treating the data with random MACs that at the time they discarded, to extend the sample of information.

3 Their current system could identify the phone and keep associating the Wi-Fi packets so it's possible to know how many time the phone spends in the area and if they come back sometime after.

..Problem solving

..Technical solution/Technolog

4 Our final system does not meet all the specifications proposed by Foot Analytics. Some of them were unobtainable due to the type of algorithm and technology we used in the project. The first one was tracking the mobile after losing sight for a long time because our system relied on keeping the phone on sight to link the packets with random MACS to their original phone. And the second one was the android phone branch, of which during the research we found they randomized in a lot of different ways and was impossible to adapt the algorithm to all of them and even having to deal with other unknown randomizing methods without compromising the result data.

5 But on our project works well with iOS phones after we analysed all types of possible randomization and is able to identify different iPhones from each other with random Macs. Which means that now the upgraded system of Foot Analytics will have a larger sample of information adding the random MACs iPhones to the old sample.

..Investigation & Knwoledge disc

6 After all the research and work done during the duration of the project we have come to some important conclusions about MAC Randomization.

..Business sense

..Investigation & Knwoledge d

7 First of all, it is important to mention the fact that this kind of technologies need a high investment in R&D, up to the point that it is almost impossible to get something that works if there is not a certain amount of research. It is important to dig into the documentation provided by the papers and to enclose this research with experimental analysis to find a pattern in the randomization.

8 However, the continuous development of technology will provide stronger ways of randomization. For example, it has been checked that iOS devices randomize more efficiently over time. With that in mind, we must make sure that our algorithm has a strong fiability over the next few years.

9 We think that these improvements will keep increasing, making harder and harder the design of newer and

effective algorithms.

..Critical thinking

10 The use of the MAC address is interpreted by relating each person with a terminal (its own MAC), with which we can obtain a global statistics of the (anonymous) people who have been in the area of interest, however its not the most efficient method due to the causes exposed on the previous paragraphs. Each smartphone has its own chip, version and vendor; all three elements create a unique randomizing way which difficultates its tracking. It has also been seen that the devices provide a lot of information to the networks around their location so, due to a civic motive of data protection, the manufacturers are quickly changing this massive information divulgation. This has a direct effect on the designed algorithms to beat MAC randomization. The comparative *time invested in research and algorithm design* vs. *randomization evolution* is biased in favour of the devices' manufacturers.

..Social impact

..Experimentation

11 The most important one is related to privacy and the amount of information we are giving for free to the net without realizing it. All this information can be used by people who knows how the network works and then use it in a variety of ways, which can have good or bad intentions. We know there are some privacy laws concerning this case, but they may not be sufficient to guarantee our network privacy. One clear example of this discussion is the Karma Attack, which even though we did some tests and verified that it could be possible to do it (not feasible), we concluded it could be used to attempt to people's privacy in a way that one could monitor all their sent data to the network, which is some development we would not like to contribute.

12 LESSONS LEARNED

13 During the development of the project we faced situations that forced us to make decisions. Some of them have been right, but some others have not. In this section, we will reflect on our right choices, but also the wrong choices in order to avoid falling back into this kind of decisions. First of all, we will discuss what went right and wrong in our project, for a good comprehension of our own critique.

14 <u>What went right?</u>

..Technical solution/Technology

15 **Writing our own code in Python:** Considering that we preferred building our own sniffer from scratch, choosing Python was one of the best choices, as there are lots of already written libraries which helped us to catch up really

fast and its downsides were not substantial to this project.

16 **iOS randomization research:** We could test with ease almost all the iOS devices that are the most common in the marked, since the beginning. This enabled us to build a self-contained iOS randomization documentation.

..Technical solution/Technology

17 **Using Raspberry:** The Raspberry configuration has been a good choice, since it is almost designed for a software similar to ours. Also, having an external antenna is also beneficial, as it gives our product an extra source of flexibility.

18 **Anechoic chamber:** Initially, we had some issues isolating mobile devices. However, the possibility of using an anechoic chamber enabled us to have significant measures about certain devices.

19 **<u>What went wrong?</u>**

20 **Android randomization research:** The lack of MAC randomizing Android devices stuck our project in certain points. Also, adding the fact that almost every Android device randomizes in a different way than the other, this crushed all sort of effort.

..Technical solution/Technology

21 **The late discovery of Weka Software:** Weka is a classification software that helped us to identify some patterns in the information that was presented in a more difficult way. We concluded that a Machine Learning software could have helped a lot if we had used it since the beginning.

22 **Installing Python3 to Foot Analytics' Access Points:** We had some issues installing Python3 and all the required Python libraries into the Access Points due to its lack of non-Volatile memory, and even if we obviate this fact, some of them could not get Python3 installed, since its software did not recognize that Package.

23 Once the project has finished, it is now the turn for reflection. In this particular scenario, we may have gained another view of Wi-Fi technology and another application of it. However, there are other ideas that we have meditated while doing this project, which we probably would never have thought about.

..Energy

..Coordination

24 Last but not least, a review has to be done in order to improve ourselves. Our performance as a group has been good, there have not been any confrontations between group members and we have been able of working on a comfortable working environment. Even so, we have to reflect on the workload of a low number of team members.

..Organization

The work distribution during the project has not been our strong point. Due to circumstances beyond our control (such as the low number of devices to analyse) we found ourselves in some cases stuck with the progress of the project but with a large number of team members without any work. We should do a self-criticism about the need of taking the initiative to find new development paths when getting stuck on a dead end.

..Communication

25 Even though, we should also take into account the good communication between the group. Thanks to the weekly meetings, all the group was kept well informed. This point needs special remarks considering that the team was composed by a large number of people.

..Self-efficacy

26 We have managed to successfully carry out our objective. We have learned about a theme that most of all knew nothing about, designed and implemented an algorithm using a raspberry and improved our team working skills in four months of intense work.

27 We are also seen in the obligation of making a review of the performance of our teachers and lecturers in order to let them know what could be improved for the next years. We have had to attend multiple seminaries which resulted useless to our project. Most of the contents of the seminaries were not applicable to our research.

28 Furthermore, an important problem has been the communication. The communication between teacher-student and the communication teacher-to-teacher. We have found ourselves with multiples doubts about the Financial plan and the Sustainability analysis. On the first one, the Financial plan, there was conflict between teachers due to the different opinions on the approach of the document. On the second one, the Sustainability analysis, there was a misunderstanding as we understood that an extensive document was required.

29 Our opinion is that these points should be taken into account to save misunderstandings in the following years.

1 **PDP_17-18_Fall_5**

..Self-efficacy
..Problem solving

2 Focusing in the finished system characterization of the prototype we can observe that results have been improved, reaching all the challenges. The prototype has good results with al kind of substrates and the effect of the diaphragm aperture has been proven.

..Technical solution/Technology

3 In terms of hardware, in this project the design of a compact TL-SOMAS has been made completely, incorporating the power supply of the laser from the Raspberry. The only final step to be done is to print it in 3D or build it. There are not final conclusions because without the real piece tests cannot be done.

..Technical solution/Technology

4 In terms of software, the main structure has remained the same, but with the changes explained above in images processing it has been possible to optimize the code. In addition, with the new placement of the window better results have been achieved.

..Experimentation

5 The new development of z sensor has not been finished. Different ideas have been proved not to be a real solution. One important aspect is the short displacement that have to be measured, this make impossible to implement some solutions that serves for bigger ones. Another big challenge is the limited pieces that can be used, the fact of trying to implement a new sensor in an already design prototype.

..Uncertainty management
..Leadership/Initiative
..Self-awareness for professio
..Self-efficacy

6 It is hard to evaluate the concept of this project because of its unconventional form. The purpose of this course was to simulate a real-life genuine engineering issue and the process of achieving its certain goals. For that reason, the influence of both organizers and lecturers was intentionally minimized (as it was possible) to allow the students develop the engineering skills of working in an organized enterprise as well as soft-skills like team cooperation and expression of self as an active, aware of his/her function in a group part of a functional "engineering organism". In that term, the organizers/ lecturers had performed their duties perfectly, because we as the group indeed began to work on our own as it was intended.

..Coordination
..Coordination
..Leadership/Initiative
..Organization
..Energy
..Problem solving

7 That brings us to the evaluation of our self as a team. Taking into consideration that for most of us (if not all of us) that was the first experience with such an advanced task in an engineering branch, the performance of the team was satisfactory. As it was mentioned before, we managed to work as a team, we've established a team leader responsible for the coordination of all the member's performance, we've divided ourselves by developing separate sub-groups responsible for different aspects of the project. In that matter, the overall productivity of the team was lucrative. Each group has achieved certain goals that were established at the beginning of the project and the final effect of our work is an operational product, which itself is a proof of our performance.

..Time management

8 Of course, following the spirit of perfectionism, the fuel of development, certain things could have been done better, taking into consideration the time that we had to work on this project, but mostly that was a result of lack of experience in such kind of activity or just simply a lack of knowledge, which is acceptable for students at the beginning of their journey into the engineering world.

..Self-awareness for professional

9 To sum up, the project was a great opportunity for the students to evolve in a domain that they did not have an opportunity before and

develop skills that are desired in contemporary engineering environment.

1 **PDP_17-18_Fall_6**

..Critical thinking
..Planning
..Critical thinking

2 After working these months with this project, we can say that we didn't hit the initial planning, since it was unrealistic for the time we had. Also, in certain aspects about the design and implementation, we have wanted to design the difficult version before having the easiest one perfectly implemented and working. An example of this would be that we implemented the sound using the sound phase, possibly if we worked first on sound amplitude, we would have avoided some problems. We have seen that one way to do an accurate design is to have a simple prototype that works and then to improve it.

..Experimentation

..Critical thinking

3 On the other hand, not all the problems have been due to the initial Planning, we also had certain limitations due to the components used or the lack of experience that we still have.

4 These problems caused us that certain goals we initially had, have not been achieved.

5 We have to differentiate these unfulfilled goals in two. The first is those problems that we could solve in a short term and the second one, those that would make us rethink the whole system.

..Technical solution/Technology

6 The first objective not achieved is to have a device cost of less than 2 euros, this is due to the fact that we used a more expensive PIC than the one we initially supposed to use. This is an example of a resolution that would make us rethink part of the system if we decide to achieve that goal and use a cheaper PIC.

7 Another problem is that the PIC's RTC only allows us to program an alarm one time per day. This is an example of the limitation that the Android group has had mixing the work of each team. We could improve with a short-term upgrade, having multiple alarms at the times we want.

8 Most of the limitations that have been taken, have been due to limitations of the hardware used, such as the LED, which has given us a lower speed and more errors than expected. This would be another problem that would involve a reconsideration of the System if we would want to solve it.

..Uncertainty management

9 In general, the organizers have guided us well during the performance warning us of the different problems that we would confront, and thus saving us a lot of time. The only thing they could have been done better is to define the tasks better at the beginning, so we could be able to assign people knowing our qualities.

..Communication

10 One of the things we could have been done better as a team is to communicate more often and more accurately between the different subgroups. We worked pretty good individually or in pairs, but this lack of communication has made us difficult to merge the work of the different groups. If we had communicated better, we would all start the work from the same point and we could avoid these problems.

..Self-efficacy
..Energy

11 Another thing that we could have been done better is to work harder since the first day. We performed hard the last month, but we wasted a lot of time working inefficiently the first weeks.

..Self-efficacy
..Coordination
..Leadership/Initiative

12 Even though we could work better improving this explained points, we should be proud of having completed a project with a group of 16 people, we were used to carry on projects in groups of two or four people. Therefore, we have improved our teamwork and in some cases, our leadership.

1 **PDP_17-18_Fall_7**

..Energy
..Problem solving
..Technical solution/Technc

2 After four months of hard work, we have finally built the system successfully. We had to buy new controllers, figure out how connect the new motor and redesign and rebuilt the PCB. After that, we made some tests that helped us to verify our system achieves the demanding speed and power consumption specifications. We realized that the spinning behavior was not perfect and had errors.

..Self-efficacy
..Technical solution/Technolog
..Organization

3 During this course, we had a lot of problems and mishaps but we could resolve them and go on with the project. We have learned to keep the calm when an error shows up since in projects the problems always come up. We have learned the phases of a satellite mission, how the satellites behave in the space, how the space environment is and all the problems that can come up in a satellite mission. We have learned how to design a PCB with the Altium project, how the servomotors work, we have improved our skills programming and we have got more knowledge about the Arduino and STM32 boards. Also, we have seen that things apparently simple such as buy a component are not really that easy, and even the most insignificantly thing has importance in the project.

..Self-efficacy
..Time management

4 In conclusion, it has been a project full of new experiences and knowledge and we are really proud of final result of our system. In the end of December, we were a little bit exhausted and worried due to the lack of time and all the things that were coming like the final exams, but finally, it has been worth. ership.

1 **PDP_17-18_Fall_8**

2 To conclude this project, the principal objectives will be reviewed and whether or not they have been achieved.

..Problem solving

3 Firstly, the main objective of the project is to detect and track the respiration of a baby and his heartbeat, and it can be considered as achieved.

..Technical solution/Technology

4 While the desired results of respiration were obtained without much complexity, the heartbeat caused much more trouble. This was due to the fact that the heartbeat has much smaller movements than the respiration, and so it becomes hard to distinguish.

5 However, it can still be detected in the abdomen. Later on, it was found that taking some measurements on the neck, pointing to the jugular vein, the heartbeat was perfectly seen.

..User awareness

..Self-efficacy

6 Furthermore, it is important to remark that there has not been yet any measurements in a more realistic situation (with newborns involved), so it is impossible to ensure the correct functioning of the system until further tests have been made. Albeit, it is true that the provisional results are very promising and offer good future perspectives.

..User awareness

7 Regarding the requirements demanded by the doctors, one that monitors the respiration and triggers the alarm if the patient has stopped breathing for more than 15 seconds has been achieved. The requirement of monitoring the patient and triggering an alarm if the patient has an epilepsy attack with tremblings in the body is still not fulfilled but will be implemented in future versions. Last but not least, it is also capable to detect if the patient does some kind of movements when they were supposed to be static.

..Critical thinking

..Self-efficacy

..Energy

8 The RADAR still has a lot of room for improvement. Nevertheless, as a first prototype, the team is glad to have reached this point. A lot of drawbacks have appeared during the process of designing the system. Nonetheless, the team has managed to overcome all these hurdles and finish the prototype.

9 In the future, some steps that can be taken in order to ensure the progression of this project would be:

10 First, designing a code that follows all the movements of the patient and knows the exact position of every part of the body at any moment. Then, the information can be displayed in a screen showing its position.

11 Second, designing a RADAR with all the components needed to be able to fully monitor more than just one patient at any time.

12 Third, making a class II power supply to not endanger the patient or users.

13 Fourth, substituting the computer processing for a Raspberry Pi in order to make the product more transportable and efficient. Also including a gadget with WIFI to send the information to the display, which may be placed away from the RADAR .

14 Fifth, implementing machine learning in order to detect different patterns of epilepsy and respiration since every patient has its unique pattern.

15 To finish this document, the lessons learned during the project will be explained.

..Communication

16 To do it in an organized way, firstly the team as a group is going to be analyzed: In conclusion, it is fair to say the team has not

..Communication
..Coordination

been as communicative as it ought to have been. Another important point is that not all team members have been equally implicated so they did not dedicate the same time to the project.

17 Regarding the specific subteams, there are six different subgroups: Digitizer (Andreu, Carlos), Electronics (DDS: Nicholas, Lorena, Laura) (PLL: Daniel, Andreu, Carlos), Power supply (Nicholas, Daniel), Processing (Marc O., Cristian) and Conditioning (Marc M., Guillem). The project leader role has been played by Carlos.

..Organization

18 The digitizer group and the processing group, as both of them worked with code, both had the same problem: the codes and measurements organization. As the code was not totally organized and many parts of the code were in many different folders not properly named, some extra time had been spent trying to figure out which was the correct one.

..Planning

19 The conditioning subteam did not take into account some design parameters before implementing the chip and this ended up causing an important delay on the whole the project.

..Leadership/Initiative
..Time management
..Coordination

20 The project leader could have pushed more some subteams. Also, some people redistribution could have been done to get the work finished earlier or better taking into account that some team members have not spent as much time as others.

..Coordination

21 Another problem is that some members did not follow the project leader instructions doing what they wanted to do, making it more difficult for the project leader.

..Organization

22 There were also members who seemed lost during a certain time of the project which meant people were wasting time and not being productive.

..Uncertainty management
..Planning

23 Also, one specific and relevant problem has been faced up during quite some time: an important parameter has been changed many times during two thirds of the project. This parameter was the definition of the signal that was going to be used. Not having this parameter clear made it impossible to conclude other parts of the project.

..Coordination

24 Although, as it has been mentioned, many issues have arose, the team has been able to overcome most problems and work together towards a common goal, making it possible to obtain a working prototype.

1 PDP_17-18_Fall_9

2 Once the project is finished, it is time to see what objectives and ambitions have been achieved by the team. To know that, we have to think what were our expectations at the start of the project:

..User awareness

3 Our project had some important objectives to accomplish in approximately 3 months:

4 • Reduce driver's distractions

5 • Avoid car accidents due to drowsiness, nervousness and stress.

6 • Make the driver experience more comfortable and personal.

..Problem solving

7 Regarding the first statement we have succeed on reducing driver's distractions by implementing a robust hand gesture recognition system with leap motion. It is fast enough to recognize the gesture made by the driver, this way the hand has to be away from the steering wheel a very short period of time instead of the large period of time the driver faced when looking for buttons and not paying enough attention to the road.

..Critical thinking
..Energy
..Investigation & Knwoledg
..Problem solving

8 The second statement was our top priority due to the importance of security itself. Although we had some limitations because the devices we used were not powerful enough to perfectly perform the operations needed to detect the different states, we investigated as much as possible to push the limits of the technologies and optimize the systems. The results have been satisfactory, we can prevent accidents by detecting drowsiness, nervousness and stress, moreover, we can anticipate those states.

..Problem solving

9 Last but not least, improving the driver experience has been accomplished thanks to the driver recognition system. All the configurations will be automatically set depending on who is the driver, this will make the system more efficient.

..Social impact
..Business sense

10 We strongly believe that the features of our project are a must have in the near future cars because it will help reducing the majority of car accidents due to distractions and the states previously mentioned. In addition, it may be true that different similar systems are being developed at the moment by other companies, but there is not any system that implements all our features in a single product as we do.

..Coordination
..Energy
..Energy
..Coordination

11 As we come to the project's close, it is crucial that we evaluate and reflect on the work done. From the beginning, we established a good relationship between all members that, added to the fact that we all were interested and motivated about the topic of the project, the job we had to do and how we could carry it out to get the best results, has been the key to the success on the plan. We all have worked smoothly and effectively as a team, pushing ourselves to do our best. Plus, we have learned a ton of new things and techniques, both from the project and from each other.

..Organization
..Planning
..Self-efficacy
..Coordination
..Energy
..Organization
..Planning

12 We have accomplished to develop the project Lear Corporation had in mind for us at the beginning of the semester, and we did it thanks to good planning and coordination, the guidance of our project supervisor, persistence and teamwork.

13 Thanks to the Time Plan we prepared when we started, we worked efficiently and have fulfilled the objectives, meeting every deadline.

14 Moreover, the seminars prepared for us gave us the necessary knowledge to carry out certain parts of the project, important for its successfully completion.

15 Obviously, there is always room for improvement and we believe there are some matters that we could either have done better or worked on if we had more time. For example, we could have developed a simple interface with all of our functionalities integrated and extend the database of recognizable emotions, states and gestures. Also, use cutting-edge techniques like deep learning or improve its precision and make it more robust, especially in dim scenarios.

..Energy

16 Overall, we are happy with our performance. We have worked hard, learned a great deal and develop a project with a performance we are satisfied of.

1 **PDP_17-18_Fall_10**

2 After finishing the project and describe its main features and aspects in the sections above, we have come up with some important conclusions.

..Self-efficacy

3 To begin with, we can state we have achieved the overall goal of the project.

..Planning

4 This has been possible due to the task assigned to different subteams formed by a variable number of workers depending on the task complexity and its deadline. Some changes have been made throughout the course to adapt the teams to new tasks' arising or the ending of the completed ones.

..Time management

5 The time plan has been a really useful tool to help meet the time limit requirements and to optimize the use of available time and human resources.

..Organization

..Communication

NETWORKING

6 Also, the weekly meetings between the team have been a useful tool to keep track of the state of the tasks, and the need for more resources. Additionally, the constant communication with the client via slack as well as the meetings we did during the project has been really useful to have feedback on the product while in development.

NETWORKING

7 We as a team, value much the satisfaction of the client towards the product and we can strongly affirm we have done our best to keep up with not only the technical requirements but also the expectations they had.

..Uncertainty management

..Investigation & Knwoledge d

8 Due to blockchain being in a completely new area there wasn't a lot of documentation available for us, so this was a big constraint when learning our way into the language, installation, and compatibility. We even found unresolved bugs of compatibility between versions

..Problem solving

9 So overall, we could say that managing to deliver a well-functioning MVP that accomplishes the success criteria is a big win.

..Critical thinking

10 Nonetheless, the product is not ready for production nor pre-production, since the counter part responsible for the front end is not ready to integrate our backend. Being this the current situation, we can't host a live event as a possibility to test our product in a real-life environment, like we discussed in early meetings.

..Self-efficacy

NETWORKING

11 Despite this fact, we can state that the client was satisfied, as much as we were with our work and the final product.

..Uncertainty management

12 We had some important issues when starting the project. The counterpart, Banc Sabadell, didn't meet with us to expose what was the project exactly going to be and what was going to be our part in it until mid-October.

..Time management
..Planning

13 Due to this starting delay, every task was accordingly delayed, giving us less effective time to develop the project.

..Energy

14 Despite the rough start, once we hit the road we were able to compensate the lack of time by working harder.

..Investigation & Knwoledge d
..Leadership/Initiative

15 We also had to learn by ourselves the majority of the stuff, since we didn't get any real support from Sabadell. Yes it's true some *blockchain experts* came by, but they didn't help us with the programming or deployment, which is what we really needed.

16 This was a pretty big drawback. We are lucky we had Carlos to help us with some parts of the contracts.

NETWORKING

17 On a side note, during all this time we didn't receive feedback from Sabadell. Our responsible lecturer, Josep Pegueroles, did a really good job reaching out to them.

18 We feel like we should write something that could have done better by Josep, but we really can't find anything bad to say, he was collaborative and helped us in any situation we needed it.

..Coordination

19 As a mixed team of 4 telecom students and 4 fib students, the teamwork was way better than one could expect, impeccable I might say. We distributed the tasks in a way everyone was bringing something on board and was happy with what he was doing. We helped each other when one of us got stuck in his task.

..Critical thinking

20 Yet it's true that we could have done better the code version control in GitHub. There were one or two times where we had the confusion of who was doing a certain part of the code, and we ended up repeating it.

..Self-efficacy
..Problem solving
..Self-efficacy

21 In the end, we were able to present a well-functioning MVP that accomplished by far the success criteria. It's true we had liked to see it in a live environment, but we think that given the time and resources we had the result was really good.

1 **PDP_17-18_Fall_11**

2 The aim of this section is to provide a general, yet critical, overview of the whole development of the project, what have we done wrong, what have we done right and some recommendations on how could further work regarding the project be structured.

..Self-efficacy

..Problem solving

3 Overall, a final working product has been achieved so we can call that a success. However this success might be analyzed block by block. The email processing and DB synchronization modules do their job. They do what they are supposed to do, their robustness has been proved and, other than further functionalities to be implemented which will be commented in the coming paragraph, no aw is to be mentioned. When it comes to the artificial intelligence module, things get in all the aspects trickier. We as a team did not believe that under any circumstances, not even given the largest of the labeled datasets, the black-box strategy might prove useful. As a consequence the sentence by sentence, or logic unit by logic unit treatment we think is the adequate one. As for the temporal references detection, the main drawback comes with it's lack of scalability since all the new cases are to be detected and implemented by hand. In spite of that, with the cases already included the vast majority of the real-life cases are covered. Lastly, regarding the intention detection, a neural network is definitely the way to go.

4 For anyone interested in resuming the project from where we are leaving it, we are now in the position of leaving some indications. First of all, take advantage of the infrastructure and DB system already set up and focus on key functionalities. Further functionalities like compatibility with other mail clients could be implemented but we do not consider it to be a priority. Priorities start from working on obtaining a big, by big I mean big labeled dataset to detect intention in sentences. It does not need to be exactly on the topic here treated, with the development in the field of transferred learning there are plenty strategies to follow.

5 Long story short, more data to feed the neural network. Additionally more labeled mails to run the tests, and much more study to re_ne the regular expressions. With not that much work and effort, the final product can be something really useful, robust and effective.

6 This last section is intended to be a wrapper for this four months long project Proejcte

7 Avan_cat d'Enginyeria has been. Project scope considerations and choices are analysed, work as a team is evaluated as well as the function of the leader and the supervisor.

8 When facing how the project should be structured an important choice was made. The development could be focused in building

a product as a whole or focusing only in the artificial intelligence / cognitive part. Due to the shortage of labeled data, the first option was our election. Whether it was correct or not we will never now but all choices bring consequences. Consequences might have been the underuse of our supervisor, expert in neural networks, or the under-performance of our model. Consequences however could also be the production of a whole usable product a thing that most likely otherwise we would have not had. Furthermore, consequences could also be a more thorough comprehension on what teamwork is really about. Teamwork is not working in a group but rather as a group.

..Coordination
..Coordination

9 Minding your business but keeping an eye on the whole thing, being proactive and helpful with your colleagues and putting always the team before your personal preferences. To that extent, having a clear objective from the very beginning might have been a motivating factor which combined with the deadlines we have tried to set upon as may have added the necessary bit of pressure this sort of projects always require.

..Coordination
..Planning

10 As a team, we might have failed in the standard newcomer mistakes. Lack of horizontal communication, unbalancing of workload, bottlenecks, ... However we have managed to organize quite adequately and share the same goals. The figure of the supervisor though might have not been used as much as we could have. Were we to have focused initially more on the deep learning side of the project, plenty of knowledge could have been transferred from him to us. The rush to release functional software might have diverted us from there. This is most likely a consequence on the way the project leader has chosen to face the problem, way closer to a real-life business scenario rather than to a college project based in learning. On the same note, at certain steps of the development the project leader might have represented a bottleneck in the software development, having taken a step aside however has helped easing the problem. Surprisingly enough, load of work has been quite well distributed according to the capacities and the time available from each of the members, so that is a point on his side.

..Communication
..Organization
..Organization
..Investigation & Knwoledge disc
..Leadership/Initiative
..Leadership/Initiative
..Organization
..Organization

11 To put the project in a nutshell, we might not be the bigger experts in neural networks but we have managed to develop a product from basically scratch. A product we are proud of. For forthcoming students though, bigger efforts should be put in providing the project with clearer specifications and benchmarks. Additionally, there are points in life where the background should come before the looks and making sure the project will have a strong structured backbone must always be more important than it just being it fancy or the name sounding cool. It is when we leave behind appearances that we get closer to truth.

..Self-efficacy
..Problem solving
..Energy
..Self-efficacy
..Uncertainty management

1 PDP_17-18_Spring_1

..Self-efficacy

2 From our proposed goals at the beginning of the project, we have accomplished most of them:

..User awareness

3 • _Design and create a Matlab standalone application that allows users to understand better the basic theory regarding orbits and thermal control.

..Problem solving

4 • _Design and manufacture the CanSat structure, taking into account all the components that must be fitted inside it.

..Technical solution/Technolog

5 • _Design and build the Ground Station: Yagi-Uda Antenna.

6 • _Be able to establish a communication between RX and TX.

7 • _Be able to give a constant supply to Arduino with the batteries.

..Critical thinking
..Problem solving
..Technical solution/Technology

8 And some of them are halfway through:

9 • _Control all the internal communications.

10 • _Attitude determination system.

..Organization

11 Although, we have had some troubles with our proposed tasks we have been able to overtake them.

..Coordination

12 This project has given us the possibility to work in a new topic with a big group of people. With it we have learned:

..Organization

13 • _How to manage a great load of work.

..Organization
..Communication

14 • _To organise ourselves and the importance of internal communication.

..Technical solution/Technology

15 • _New specialised topics regarding spacecrafts.

..Coordination

16 The participation in this PAE has given us a new perspective on team work and which mistakes made lead us to not accomplish a dateline. This may be very helpful for new projects to come.

1 **PDP_17-18_Spring_2**

NETWORKING
..Self-efficacy
..Problem solving
..Business sense
..Self-efficacy
..Problem solving
..Problem solving

2 When Bmat proposed this project, they came to us with a problem and ideas of tools that could help solving it. Four months later we can say that we have succeeded on arriving to a basic solution. Using Blockchain Technology we have successfully tackled the royalty distribution problem. With the help of the watermarking system, we provide a reliable way of unequivocally identifying a song with all the parties that have to benefit from it. And last but not least, with our user-friendly desktop app, we provide an easy way of interacting between our system's structures.

..Critical thinking
..Critical thinking

3 However, there is still room for improvement. As said in the previous paragraph we have come to a basic solution: We have just considered and implemented a solution for two basic use cases, that although they are the most general ones, other specific use cases could be defined and implemented. In the audio watermarking field there is a lot of improvement that can be made, regarding the robust of unusual attacks. Also, we have just considered the most important parameters of the cwr files, although we have been working with real parameters of music industry contracts. Therefore, it should not take long to parse a cwr file in its whole. Maybe the product couldn't be out in the market and fully operational by tomorrow, nonetheless, the commercial product would not be very far from what we have now.

..Communication
..Organization
..Planning
..Planning

4 One thing that could have been done better during the Project development is the handling of the communication and workplan with the enterprise. The work plan we established with Bmat, turned out to be very profitable but it was a little bit incompatible with the planning we had to do with the school. Sometimes it felt like we were planning everything twice. We think that a better way of planning mandatory meetings and documents that adapts to the nature of each project can be achieved. Another aspect we could have done better as a group is a fact of defining the use cases earlier because once we did that we could understand much better where we were heading to.

..Self-efficacy
..Coordination
..Self-efficacy
..Social impact

5 It is not a good practice to end a project talking about the bad things it had, so despite everything said above we are very happy with the final product. And we want to say that all of us have enjoyed working all together in the development of this project, and we hope with this we are putting the first brick for the construction of a new and better music industry.

6 At last but not least, we would like to thank everyone who has helped us during the development of the project especially the assistant professors Climent, Umair and Josep; and Bmat representatives Dani, Enric and Quimi. Without them, we would not have been conducted to success.

1 **PDP_17-18_Spring_3**

[..Planning] [..Self-efficacy]

2 Finally we can conclude that our project was a first experimentation for all the team with powder sensor design. Our team have had to think and implement an industrial solution for the challenge proposed. Our main difficulty have been the constant planning changes, consequence of poor planning. For the other part, we have achieved the major part of the main objectives, all specifications objectives were achieved for 2 of the 3 sensors developed.

3 The time lost have closed the third sensor work path but it's ready for future development if the project is relieve in following PAE.

[..Problem solving]

4 We can say that all our solutions are viable, and now that are assembled, they are ready for a second testing stage with improvement in any level.

[..Coordination] [..Coordination] [..Coordination]

5 At team level, it's the first time that all members of this PAE group have worked together. Some members were more comfortable working with previously known members or degree speciality roommates. But instantly good fellowship was born and after little time it was not a problem to work all together. In general, the most part of the team have resolved their individual challenges and have worked in the measure of the expected quantity and quality of work. Common challenges were resolved in group.

6 The team members have resolved technical problems, adapted them to the proposed solution and take conclusions.

[..Leadership/Initiative]

7 The team leader and the secretary have participate in the Project Plan final presentation and technical final presentation.

[..Organization]

8 The team members have worked actively in their individual tasks after lab sessions and have worked actively in their individual and mutual tasks during lab sessions.

9 The team leader have revised each deliverable document before limit time.

[..Organization]

10 All deliverable documents were submitted at time or have been delivered with data accordance with the tutors.

[NETWORKING]

11 The client members were informed periodically of meetings, changes, information reception or secondary tasks related with the main project.

[..Multidisciplinarity]

12 In this project we have took to practice a multidisciplinary team project to develop a solution.

13 As the project has arrived to an end, the team members have meditated on what aspects of the project we could have improved, and which have gone well. Now we list them with iconic phrases for easier remembering, for future projects and to advise future PAE students.

[..Planning]

14 • _*By failing to prepare, you are preparing to fail – Benjamin Franklin.* Our poor planning have affected one of the work paths producing large delays, also it has affected the final characterization of the other two good paths.

15 • _*Knowing when to retire is as important as knowing when*

..Time management

to insist - . After knowing we were expending more time than expected in the flow-meter work path, and predicting that we would expend more time in it. An intelligent solution would be to close the work path to concentrate our efforts in improving the other 2. Don't be afraid to stop a work line.

16 Also, from another point of view, if we have seen that 2 sensors where working well, we should have insisted in them to improve more the final solutions.

..Leadership/Initiative

..Coordination

..Coordination

..Time management

17 • _*Divide and Rule* - . We have not only assigned the Team Leader and Secretary, for our project structure we have had a specialist in circuit design and welding and a specialist in 3D pieces. As more dedicated roles were distributed, the team members have had more defined jobs. This has avoided situations like non-productive time for this team members. For another part, the nonspecific roles and more polyvalent members, as them have not specific jobs, sometimes time was lost.

..Organization

18 • _*Document, implement, report and repeat -.* A simple methodology to have continue report of the work done. Sometimes some members didn't document previously the implementation of a design and this have produced time lost. Also reporting results after laboratory work was done, makes easier the project plan control.

19 It could be seen a tedious job but it's necessary.

..Idea generation

..Investigation & Knwoledge discove

..Planning

20 • _*New information makes possible new ideas –.* Sometimes information that seems relevant from the client product has been delivered too late and we have needed to recalculate some parts of our designs. Also sometimes the new information was not relevant in our calculus and we have lost time trying to interpret it when it was a job to be done the first weeks of the project.

1 **PDP_17-18_Spring_4**

..Self-efficacy

2 After having finished this project, we think it’s important to look back at all the things we have achieved during the process of this work and the things we have learned in different engineering aspects. We don’t want only to look at that, but also to make a self-criticism of our work as a team and how we have achieved or not the initial objectives of the project

..Uncertainty management
..Investigation & Knwoledge d
..Energy

3 We came from a point in which all of us had no idea about the spring framework for java microservices projects and it was the principal element of our project because the backend is based in a springboot project. From the beginning we had to learn everything about spring boot, and how we did everything.

..Coordination
..Critical thinking

4 To finish, although all of have worked in small projects and have already been involved in some team-up work, this was clearly a step forward in this field for all of us. We have never really worked in a project that big, maybe it was too big as we couldn’t finish it all.

..Time management
..Time management

5 Time was really an issue in this project. At the beginning of the project, we spent a lot of time advancing in a really slow mode, although it is perfectly normal, as we didn’t really know how things worked (GitHub facilities above all). That took away almost 2 months of work that could have been really valuable by the end of the project. The fact that all of us had examination tests at the University also slowed the advance of the project severely and took away a lot of our time as well.

..Energy
..Critical thinking

6 Overall, we came to the conclusion that this project isn’t something easy to do in a month or two, and, despite all the hard work of all of us, we didn’t reach the final objective because we did not add the prediction we expected in the project initial scope and, how we said at the beginning of the document, we also did not implement the session control of users.

..Time management

7 Factors like time and complexity were crucial during the project. All of us have learned at least one programming framework or improved another like MATLAB or SQL.

..Business sense
..Organization

8 From the beginning we have been using the Agile method which means that every two weeks (every sprint) we have been changing some aspects of the business plan. Who would be the clients, where would the software be running and so on. In the beginning we defined the sprints deliberately without knowing what we would like to achieve in each one, after the first one we decided to have the ideas defined and all the objectives numbered and detailed this way we could have a better organization.

..Problem solving
..Idea generation

9 Firstly, we wanted it to be for every type of infrastructure, but later we realized that we could do a universal software but we couldn’t do it that easily, so we changed the clients use, this is, the product would be focused on closed infrastructures. Later we had some ideas that could change again our management plan, and that could be again available to any client. It could be used to both, open infrastructures or closed infrastructures. Therefore, we changed it again and we had to developed some other aspects of the project.

10 There are some aspects of the project we could have made better: these are the following ones.

11 - The initial dissertation of the system architecture did not take into

account risk cases and in half project, we had to make some design changes.

..Organization
..Communication

12 - The initial communication was not quite useful as we did not explain to other members what each one was doing and we collided with others in some things that we implemented at the same time.

13 - We did not used Git completely with the Git workflow and it was used as a repository but rather as a version controller.

1 **PDP_17-18_Spring_5**

..User awareness
..User awareness
..User awareness
..Technical solution/Technology

2 The objective of this project was to build the Enterprises functionality of Goin, an app that is now in the market and is helping young people save money in an easy way. Keeping the same concept of an easy (and secure) way to help save money, we moved the target consumer from young people to companies, and in doing so we realized we had to think of many other concepts, such as the fact that there would be an administrator or that people might have expenses of different types and companies might assign different budgets to each type. We also wanted to develop this project using innovative technologies such as the blockchain and Machine Learning, which would make our project faster, smarter and more secure.

..Problem solving
..Technical solution/Technolog

3 During the project we ran against some difficulties, like the fact that Blockchain, being such a new technology, doesn't have well defined standards and the implementation of some parts of the technology changes with a very high frequency, so we had to change the code during the project. Another thing we had to deal with was the fact that the different banks Goin uses as sources provide information in different formats, and sometimes even different pieces of information, so we had to think of a standard template for all the kinds of transactions.

..Organization
..Communication
NETWORKING

4 Working with agile methodologies allowed us to quickly iterate over a the project, so every week we were able to see how the solution we were creating evolved and the different parts developed until the last weeks we were able to merge the different parts together. We were also able to communicate effectively and frequently with the project owner, so after every few sprints we could show the parts that were finished and use the feedback he gave us to make the necessary changes or add work to the backlog in order to arrive to a solution that perfectly suited his needs.

..Self-efficacy

5 If we read the initial objectives that we defined during the first meetings with the project owner, we set our goals at developing a service that would allow companies to save money using machine learning, we wanted to secure it and provide auditability using the blockchain, and allow for ID-recognition using image processing too. Looking back our work and the product we made we can finally say: we did it.

..Coordination
..Self-efficacy

6 The overall team performance was positive. We have achieved our main goal, that was the development of a first version of the Goin for Enterprise software. Every team has developed its part of the project successfully, achieving a functional software.

7 Some things to improve for the next project are:

..Communication

8 • _The communication between teams regarding the final integration was sometimes a little bit confusing. In future projects, we will have to empathize this part since it is crucial for the final result.

..Uncertainty management
..Organization
..Planning

9 • _Having a clear idea of the general schema of the project is important. There were some points that we were not sure of that schema, due to the complexity of some parts and the fact that

..Planning
..Organization

10

most had to learn from scratch about the technologies we were using.
• _Using the Agile methodology was new for some of us. This made that some of the sprints were not completely achieved as we didn't made a good calculation of the history points of the tasks.

1 **PDP_17-18_Spring_6**

2 Once this project is wrapped up, we feel it's important to take a look back at what things we have achieved during the process of his work and what things we have learned in different engineering aspects and how to work as a team.

..Uncertainty management

3 We came from a point where all of us had never had concepts about data quality. Apart from this, the programming languages that we used, most of the equipment we had never seen. None of us was an expert in databases, or frameworks and many other new concepts for us.

..Uncertainty management

4 To finish, although all of have worked in small projects and have already been involved in some team-up work, we have never really worked in a project that big, maybe it was too big as we couldn't finish it all.

..Time management
..Time management
..Uncertainty management

5 Time was really an issue in this project. At the beginning of the project, we spent a lot of time advancing in a really slow mode, as we didn't really know how things worked . That took away almost 3 weeks of work that could have been really valuable by the end of the project.

..Time management
..Organization
..Communication
..Organization

6 We have understood that we need to divide the work in groups to grow faster and cleverer, but the point that has make us all united is that no matter if one person was working on something completely different than other one, we just talk each other to know how was the progress of each part and we all have a wide and concise view of the whole project. The start week on Mondays and extra work meetings we did to decide how to proceed in our project, done together, was the fuel to keep the global project evolution forward.

..Critical thinking
..Self-efficacy

7 Overall, we came to the conclusion that this project isn't something easy to do in three month, and, despite all the hard work of all of us, we didn't reach the final objective. Because this project has been delivered with many objectives to achieve, but we focused on making a first version, the functional version of the application, and we got it. In the future we can finish some of the goals that we have not been able to reach such as the creation of a dictionary, traceability, blockchain, etc.

..Self-efficacy
..Communication
..Organization

8 The members of the team are really proud of the results, giving that the progress made since the beginning is awesome. All of us have learned at least one programming language, have acquired a lot of knowledge of databases how to structure a project and that communication between the members of the team is very important to advance and speed up the progress of the project.

9 Here it is going to be described how the relation with the professors and clients has been, and also how the team has been organized.

..Communication

10 The relationship with the teachers has been excellent, there has been very good communication, and they have always been receptive when it comes to helping with any problem we have had in the project and they have facilitated access to UPC technologies. We appreciate the treatment they have had with us.

..Communication
NETWORKING

11 The communication with the Minsait has been also excellent, every week they met with us and we explained to them the progress of the project and the problems and doubts that we found, and they helped us to solve the doubts, which is to be appreciated, since it has facilitated our work. Really, they have always been receptive and have helped the development of the project.

..Uncertainty management

12 The only thing that could be better done by organizers is to clarify the initial request to start the project, because we spent many weeks until we whole understand what they wanted us to do.

..Communication
..Coordination

13 We could communicate the work done to each other not better but more often, to keep us all more updated.

..Communication
..Coordination

14 We have worked very well as a team. At first we did not know each other, we were just students who had coincided in some subjects or who had seen each other on campus. Over the weeks we were formed as a team end ended up being a group of engineers who communicated, related and shared ideas in common in an efficient way and enjoying

..Communication
..Coordination
..Self-efficacy
..Self-efficacy

the project.

15 On balance, this project is the evidence of evolution, learning and improvement from a basic knowledge and skills related to the implementation software. In our opinion this is a remarkable accomplishment given the short timeframe in which the project was executed. Therefore, keeping the evolution tracking, we feel able to do better organization and task assignment in a future projects

1 **PDP_17-18_Spring_7**

2 Once explained the purpose and the motivation of the project, as well as his design or some other features like the costs or the sustainability, we can do a great balance of this project.

..Business sense
..Sustainability

3 We have learned and we have gone inside into a new revolutionary technology that will be very protagonist soon, and we will be there to develop in it. We have to take profit of this project, because it has brought us another vision of how can be a decentralized system, like Blockchain.

..Self-efficacy
..Technical solution/Technolog
..Self-efficacy
..Problem solving

4 We also have developed in some new programming languages. One of them, Solidity that allows us to program Smart Contracts, the most important part to build a Blockchain system. Another language that some of us have learned is React, a Javascript Framework. This language is very useful in a system with different states that has to change accordingly with a backend. In our project this framework has been very comfortable to develop this job.

..Technical solution/Technolog
..Technical solution/Technolog
..Technical solution/Technology

5 Moreover, there has been some things to improve, and some things that we guessed, and for this facts we have to be proud of us. Besides, there has been some impediments from the owners of the project. All of this details are reflected in the next section.

..Self-efficacy

6 Concerning to the organization we have brought, we will go into more details in the next section too, but we can say that we have organized well. We went together at the same time in the formation process, where Jose Luis Muñoz gave us some videos to familiarize ourselves with this technology. Then, once we have finished this process, we designed the structure of our project. From here until the end, we divided our group into two small groups. One of the groups started to develop the backend part of the project, based in Smart Contracts programmed in Solidity and the other group continued with the formation part learning React, to do the frontend. Then, both groups worked separately but always in contact, to get the best efficiency to the project. Finally, together we unified all of the parts and we delivered the final product.

..Organization
..Organization
..Organization
..Organization
..Technical solution/Technc
..Technical solution/Technc
..Organization
..Coordination

7 This project, for most of the participants on it, is the first big project that we have developed. Of course, we have done things well, things that we have to improve for the next time and things that we have to organize better, to take more profit. Moreover, from the owners of the project, we also have some complains about the organization. Here in this section, we will analyze this points and we will make a brief reflection of the project.

8 First of all, we have to have clear what we've learned among this four months about a new technology like Blockchain. This allows us to go deeper into this topic and we have more than the fundamentals to develop whatever with it. We have to value a lot this knowledge and take profit of it when we go into the world of work.

..Technical solution/Technology
..Self-awareness for professional

9 Another important thing to value is the experience we have taken with a big business like Banc Sabadell. It's very different the university life than dealing with a big business. Here we have seen how they work and the dynamic of bringing a project of this

..Self-awareness for professio
NETWORKING

..Self-awareness for professio
NETWORKING
..Critical thinking
..Organization

dimensions, so if we are another time into a situation like this, we will know how we have to behave. Therefore, the experience of become into a big project is the other thing that we take.

10 There has been things that we have to improve too. One of them is the organization that we have taken. Surely, we should have organized better. During the project, we have gone together during all of the formation process and also when we have designed the project. Then, some of ours finished the backend part, others did the frontend and others prepared the costs of the project. For the benefit of the project, the better procedure would have been the specialization of everyone in one thing. Then, we have had more time to develop the project. Even so, it's also true that we haven't learned so much due to the specialization from the first moment into different tasks.

..Organization

NETWORKING

11 One of the things to improve from the owners of the project is the low attention that was lend by Banc Sabadell. We have been doing calls with them, but most of the time we have talked with CTTIC (an Asturian group that have helped us with the most technical part) and very few with Banc Sabadell. In addition to this, some critics arrived later, like the no explanation of the Project Design Review, when our group remind to Banc Sabadell about doing this exposition a couple of times.

..Self-efficacy
..Coordination

12 Definitely, we have work very well. We have got along with ourselves and we have understood between us. It's certain that we have only 5 students and most of us knew each other before, but it's very easy to have discrepancies and misunderstandings. In general, from the group, we have a great balance of the project and how we have worked among this months.

1 **PDP_17-18_Spring_8**

2 We shall conclude this document commenting whether the objectives of the project have been accomplished or not.

..Self-efficacy
..Problem solving

3 The initial challenge was to “design and develop a culinary chatbot that given an image input provides matching recipes”. From this point of view, we believe that we have succeeded, with excellent performance as our product provides this feature and many more such as text correction and video recipes.

..Critical thinking
..Organization

4 However, we set high standards that were not accomplished like saving the preferences of the users or their allergies. That was mainly because the time planned for those tasks was devoted to make the system more reliable and robust. Those efforts were worth them because in the final presentation the product worked fine.

..Business sense

5 The business part of the project also filled the expectations we had. The business approach we developed was coherent with the kind of project and the calculations of the costs were both low enough to be competitive and high enough to be profitable for the company we imagined.

..Time management

6 Timings were also respected due to the many hours assigned to the subject and to the commitment and dedication of the team.

..Energy
..Self-efficacy
..Self-awareness for professio

7 Overall, this project, thanks to the hard work of the team, has been a complete success and the learnings from it will help us in the future.

8 We believe that having this subject been held for so many years, it’s organisation works fine. For the technical part the business seminars are a little bit disconnected between them and have no relation with the actual projects. Maybe the aim of the seminar courses is so broad that it loses its track sometimes.

..Uncertainty management

9 For the technical side of the subject the course has run smoothly. Maybe sometimes we had the feeling that nothing was defined, but it has not a negative nature as students are too used to follow orders rather than creating their own path. Having to think about what to do and next steps is a good way to learn this skills.

..Coordination
..Energy
..Coordination

10 The group performance has been great having everyone committed to the project even when the work required for other subjects was high. We are happy with the team performance as each team member has been responsible and accountable for her work.

1 **PDP_17-18_Spring_9**

..Problem solving

2 This version of the prototype stage has brought the project to a solid point in terms of optimization, trustable data, and market preparation.

..Technical solution/Tec
..Problem solving
..Problem solving
..Technical solution/Tec
..Technical solution/Technolog
..Problem solving

3 It has been achieved that the radar could take measurements in real time, which is an important accomplishment towards the evolution of the project. Plus, a complete architecture for the radar has been built and a display for monitoring the vital signs has been designed, which also include the heartbeat frequency, breath rate and alarms in case of tachycardia, bradycardia and apnea. Furthermore, this version is more stable than the last one because the noise of the radar has been reduced when signals from both channels I&Q are acquired. Summarizing, the device is suitable for testing in a medical environment.

..Critical thinking
..Self-efficacy
..Technical solution/Technology

4 Even the main goals for this project have been accomplished, it is clearly known that this will not be the last version of the prototype. In the future, this project will need to investigate with a greater campaign of measures to solve some issues related to the acquisition of the signal.

..User awareness

5 For example, optimal results were obtained when testing with members of the group, in a specific position and pointing exactly at the chest without letting the person move. But it is unknown what could happen in a medical environment, with different patients that could have possible heart or breath disorders.

..Technical solution/Technology

6 Also, as the radar is so precise, the processing of the signal will have to be improved if a clearer signal with less interferences is desired.

..Communication
..Organization

7 The team had learnt the importance of organizing properly, as well as communicating with each other if to solve the issues encountered during this project.

..Organization
..Planning

8 First, the organization is crucial because designing a prototype includes to encounter unexpected issues and it is important to have a backup plan in case of any problem.

..Organization

9 Second, the tasks started in parallel but that was useful until to a certain point, where it has to be decided how the integration of the system had to be done.

..Organization

10 Finally, it was important to learn to focus on what it had to be achieved and try to not spend too much time doing secondary tasks which were not as important as the main ones.

..Self-efficacy

11 To conclude, even it had been ups and downs during these weeks, the improvements made are really satisfactory because the project evolved to a great degree which is considerable enough to be presented in a medical environment

12 This last section is dedicated to explain everything that had been learned and what could be improved in a future project. This part of the report is divided into different areas for a better understanding.

..Uncertainty management

13 First, it must be mentioned the scope of this project. Since it had a prime prototype before, it was a little complicated to connect with this project, hence the documents of our previous

..Self-efficacy
..Time management
..Organization
..Organization
..Communication

colleagues were not helpful at all due to the lack of information they contained. However, all the goals set for this project practically have been accomplished. Some of the tasks were not performed as expected, due to the lack of time mainly and the injuries caused by some members of the group. Consequently, some priorities had to be rearranged and rush in the last weeks to get the tasks done. So, in future projects the organization may be more rigorous and the communication in between the team should be more active as well.

..Time management
..Coordination
..Planning
..Organization
..Leadership/Initiative

14 As it has been mentioned before, another determinant has been the time. As every individual of the team works differently, the group suffered from destructive dynamics in some way. For example, when some document or some task had to be delivered, the team was on a rush because some members waited until the last minute to get it done. This means that some members could have taken more initiative into the project.

..Business sense

15 Otherwise, there was not any type of issue with the costs. Even that some pieces ordered online took longer than estimated to arrive and the team could have been more persistent to get them, a successful business plan was reached.

..Planning
..Organization

16 Some risks that had not been considered at the begin of the project were one of the most damaging factors to the team. For example, the absence caused by some team members due to the political situation in our country and certain events. This was not perjudicial until to a certain point where the cooperation was key to advance with the project. In addition, the respective members have not fully recovered the hours lost due to these events. So in the next project, there would useful to have a time cushion for each task and be more demanding with the working hours.

..Leadership/Initiative
..Communication
..Communication

17 The next area is the communication. The project leader has had good communication with her colleagues. She was informing at every moment about the advances, problems, deadlines, etc. that the team have been through. She has also shown availability to be able to communicate with her easily at any time. Something that she could do better was to spend more time in the weekly meetings with her colleagues, even though the time in the laboratory was limited. Also, it is necessary to emphasize that some schoolmate did not give feedback to questions that did the leader for the good operation of the group.

..Coordination
..Energy

18 Another aspect to comment about human resources is that some members did not follow the leader's instructions. This hindered the coordination and organization of the project. However, most of the group members made a great effort to pull the project forward and tried to keep together during the last days, that were the toughest ones.

..Planning
..Planning
..Time management

19 In addition, some components of the group have not dedicated the same time and effort. Perhaps it was due to a poor planning of the tasks resulting from the lack of experience in this field. Some people were lost when they finished their first tasks. Despite all these problems, most of them were solved properly. This mean that most of the procurements proposed at the Preliminary Design Review were achieved. However, some of

..Time management
..Organization

..Self-efficacy
..Problem solving
..Critical thinking

20

them have not been reached as it was desired because of the lack of time and organization. For example, to show a perfect signal on the display it has not been achieved.
Finally, in terms of quality, the product is prepared for a first pilot testing in the hospital, so pretty good results have been achieved. Even though, there is a big need on improving some aspects to have a reliable product.

1 PDP_18_19_Fall_1

2 Now, we proceed to summarize the main conclusions we learned while working into this project.

..Self-awareness for professio
..Business sense

3 From what real life aspects is concerned, understanding what net salary and gross salary are is an important point to take into account in planification. Also, that they are less than the total amount paid by the company. How taxes and deductions affect your salary it is also an important point. Finally, the cost associated to objects purchased for the project does not correspond with the cost they have associated, but to the devaluation of value they experience (the remaining value is still yours).

..Sustainability
..Self-awareness for profes
..Social impact

4 Explaining how our engineering impacts over society and over the environment is something that always will be demanded by any entity. A thought in the design phase can make a difference. It is too easy to forget about how small actions such a sending an e-mail can impact over the world. That is why we, as engineers, have to keep in mind how our products and services use resources and end their useful life.

..Uncertainty management
..Planning

5 Risk management: when coordinating a project, we often plan until the smallest detail, assuming that all will go as planned. However, fate usually follows another path. That is why management is not only about planning work, but about designing strategies to cope with errors when they arrive, too.

..Coordination

6 Coordination among members of the team is something crucial in order to assign and perform the different tasks of the project in order to ensure that tasks that are performed by the different members are in sintony.

..Organization
..Communication

7 A good organization is achieved by a fluent communication among the members of the team. In our project, the usage of Slack allowed us to keep in contact with our supervisors most of the time and also among ourselves.

..Technical solution/Technology

8 The knowledge of the tools used in the project development is very important to achieve the goals. Some drawbacks we had at the beginning of the project were learning the functionalities of certain tools like NS3 or GitHub and we had to spend more time in installing and learning its usage before starting working in the project.

..Critical thinking
..Problem solving

9 Although the concepts and the functionalities of the system are clear fou us, we have not been able to perform a full performance of the system. Due to the lack of time and the complexity of the project, the had to face drawbacks which took a lot of time.

..Technical solution/Technology

10 Although the different components simulated are not linked and coordinated in the simulation. The different components by themselves perform correctly, so we can assume that we have achieved the correct simulation of different components of the satellite.

..Critical thinking

11 Even though the project has been completed satisfactorily there are several points where improvements can be done.

12 On the organizers/lecturers side, we have found a lot of problems to assist to the lectures and seminars because most of them have been done in hours that were not the ones originally scheduled. Since the students choose their subjects taking into account the schedules published in the school's web, the ones who have classes in the hours where the PAE lectures really take place find the disadvantage of not being able to assist this classes and the need to schedule more hours to deliver the required presentations.

..Uncertainty management
..Uncertainty management

13 Also having a list of all the deliverables at the start of the course could ease the tasks of organization of the teams. Some deliverables of the "teoric" part have collided in time with the deliverables of the "practical" part. This causes a diminishment in the quality of both documents. We think that this could be avoided by knowing all the deadlines in advance, or at least an approximated date that would allow the students to planificate their work.

..Organization

14 On the students side, lack of coordination ralentized the work during

..Organization
..Coordination
..Communication

the first weeks, this was solved and an improvement in our teamwork was seen, but more communication and mutual help could have achieved this results earlier in the project.

1 **PDP_18_19_Fall_2**

..Problem solving
..Self-efficacy

2 As always in life, we had to face many problems during this project, most of them previously explained in this document. However, eventually, we managed to achieve our goals and make a functional system. One of our purposes was to integrate every subsystem together but we couldn't do it for a matter of time.

..Critical thinking
..Technical solution/Technology
..Self-efficacy

3 All in all, we built the three main subsystems of a CubeSat, taking everything into account (space regulations, space conditions, etc). In the end, we are satisfied that most of what we did has correctly worked.

4 We consider that the subject has been a great opportunity to put the contents learned during the degree into practice. Our teacher, Adriano Camps, invested many hours and put a lot of effort in teaching us many things about satellites and space science. Therefore, we would like to thank him and the members of the NanoSat lab for their time and for everything they taught us. We have no complaints about the lectures / organization of the subject.

..Organization
..Communication
..Coordination
..Energy

5 The project was based on three different subsystems: every subsystem needed to communicate and every subgroup did so through weekly meetings. All the subgroups worked well even though more meetings were needed as many things were strongly related and we could have saved time facing some problems together before asking teachers or members of the Nanosat lab. However, we were able to work hard obtaining good and satisfying results.

6 All of this would not have been possible without the help of Adriano, the members of the NanoSat lab, and the lab masters Joaquim Giner and Albert Martón.

PDP_18_19_Fall_3

..Self-efficacy

2 This project helped the whole team achieve a system of a certain complexity.

..Problem solving
..Technical solution/Technolog

3 In terms of the design aspect of the project, we had to create and design a functional system from and initial idea. On top of that, it was required to do with the hardware provided, which challenged us to take into consideration all the restrictions the devices had.

..Technical solution/Technology
..Technical solution/Technolog

4 Also, this project is developed with a lot of new technologies and concepts such as neural networks or Internet of Things leading us to implement solutions based on rising tech which will be widely used in the near future. We consider that this gave us a more practical approach to these topics and that implementing them has helped us understand and learn more about them.

..Technical solution/Technolog

5 At the end, the implementation of the system led to a functional prototype of the initial idea. We accomplished to create a product that behaves as we intended, and even though we encountered some problems and restrictions during the process we managed to solve them either changing the methodology or the performance of the system. This resulted in solving problems such as network saturation.

..Problem solving
..Business sense
..Technical solution/Technc

6 The success of this project proves that a Smart House system can be implemented differently from those currently out in the market.

..Problem solving
..Self-efficacy
..User awareness
..User awareness

7 Additionally, we are also satisfied with the fact that the product is very useful and can help many people in different situations. As mentioned, it is also very easy to install to any home and that may make it more appealing in front of those systems that require special devices to work, such as light bulbs with Wi-Fi.

..Self-efficacy
..Coordination
..Organization
..Communication

8 Overall, we are pleased with our product and the results. From an initial idea we managed to design and implement a system that works properly and with satisfactory results. An important part of this success comes from the fact that we worked together as a team, especially in the last part. In the beginning, we were divided in smaller groups working in the different parts, however when it came to the end of the project, the integration of those parts, the good and constant communication we maintained between teams helped bring together the final product.

..Organization

9 Our team started well, defining tasks and equally splitting them to each member, but when the project became a little changed and some tasks just disappear, we were not able to redistribute the remaining task well and it end up with members with very low work in somepoints of the project.

..Organization
..Technical solution/Technolog
..Technical solution/Technology

10 An other thing that our team could have been done better is prioritizing tasks, for example the audio stream between the micro controller and the server, one of the key features of our project, was one of the last things we implemented, and it was a time consuming feature to correctly implement and as a consequence the code of the two modules that communicates in that point needed to be partially re-writed, which is far from ideal.

..Technical solution/Technology

11 We used Github as a code version control, but at the beginning

..Technical solution/Technology
..Technical solution/Technolog

we used it wrongly, we try to work all on the same branch, which became a problem with marges and force us to create new branches and at the end look between them to ensure we don’t lose anything on the way. At mid-end term we finally change our use of Github, and every ‘bug fix’ or any minimal improvement has its own short live branch which is merged via pull request when the objective is completed. The first wrong use of the source version control cause us to lose time doing things that at the end we didn’t need to do anymore.

..Planning
NETWORKING
..Organization

12 In the other hand, some tasks become very hard, and time expensive, and finally a bottleneck in the overall development and deployment of our prototype. This could probably be solved by asking for help and testing real connections between modules before that it has been done. This should not only allow us to finish the prototype before we did, but also to try to add more features that we thought that could be great but not indispensable.

..Organization
..Technical solution/Technc
..Technical solution/Technc

13 At the end of the project we had some bugs to fix as we've said, and those bugs was mostly troubleshooted by someone different that the one who implemented the corresponding module, and even different people at the same time. The problem comes when the tests done to troubleshoot were not documented in any way and the changes that has been done in order to try to fix the bug, in the best case has a comment in the code that says what problem solves and why that way. The problem we had with this methodology is that we repeat test between us and undo things that was already tested and verified cause of that.

..Communication

14 We improve our communication methodology when we identify that problem by writing in a whatsapp group what we test and what is the result every time we think it is relevant.

1 **PDP_18_19_Fall_4**

2 Once the chatbot has been finished, we have reached the following conclusions:

..Coordination
..Time management

3 • _The group worked and cooperated during the realization of the project, meeting all the deadlines.

..Self-efficacy
..Problem solving
..User awareness

4 • _The established goals have been achieved. Now we have got a customized chatbot (with diets, intolerances and favourite recipes), with our own recognition system and a user-friendly interface.

..Critical thinking

5 • _The object-detection system sometimes work slow and don’t have much accuracy, but taking into account that it was the most difficult part of the project, the whole group is very satisfied with the results obtained.

..Technical solution/Technology

6 • _One of the greatest improvements of this version of the chatbot is that there is no dependence to third parties such as Amazon Web Services or Spoonacular.

..Communication

7 • _The whole team have managed to prepare oral-expositions in front of the teachers and Accenture managers, performing great presentations.

8 In this section of the document we will make an evaluation of the process we followed to develop the project and the different roles of the team.

..Communication

9 To start, let’s talk about the professors. They did a great job, always available to help us and answering all of our questions. The communication between the University (UPC) and the company (Accenture) was very fluid. We think that communication was one of the strengths of this project because the three entities of it (Company, University and the Team) were constantly in touch.

..Coordination
..Energy
..Self-efficacy
..Organization
..Communication

10 The team performance was also great. We achieved all of our goals working hard. One of our weaknesses has been the integration of the four work packages that made the project. We worked independently and then the integration was harder to perform. However, as we said before, the communication was a key factor, including internal communication of the team.

..Self-efficacy
NETWORKING

11 We have had some difficulties during the project, but finally we managed to finish it getting satisfactory results. We are happy with the result of our work, and we think that both UPC and Accenture as well.

1 **PDP_18_19_Fall_5**

..Uncertainty management
..Energy

2 We did not have an easy time. We worked hard to achieve this. However, in the end, we think that our work was not in vain.

..Investigation & Knwoledge disc

3 Through the entire project, we learned a lot. We started by understanding everything that was involving our project. First, our professor explained us the fundamentals of everything, from every cryptography aspect to the newest blockchain technologies, so

4 we could later on investigate by ourselves all those little things we encountered while developing the project.

..Self-efficacy
..Energy

5 Now that this has ended, and looking backwards what we have done, we can say that we accomplished almost everything that we stated at the beginning. It was not easy, and we found many problems, but we ended up with something we can say we are proud of.

..Self-efficacy
..Coordination
..Organization
..Organization

6 We also had to work together, as a team. By understanding how deep this project was, we also understood that if we did not divide the work properly, we could not achieve what we had to. At the beginning, this was challenging, but we managed to organize all

7 the work we did with weekly meetings including every member of the group and other tools like trellis or telegram.

..Uncertainty management

8 In addition, we did found many problems. Some of those worth mentioning are, for example, the overall difficulty that involved this project and made us learn a lot before getting into work, or the big amount of different technologies that our application

..Coordination
..Problem solving

9 implements. Either way, we ended up solving those problems by working together, as a team, and not as individuals.

..Coordination
..Energy

10 In summary, the results obtained are actually good. Despite every limitation we had, we managed to work as a team by developing and organizing every little task as a hardworking individual.

11 This last part of the final report, will be dedicated to some explanation of the decisions and considerations that, as a team (members and organizers), we have gone through and we think we could have done better or in a different way along those 6 months of

12 “Projecte Avançat d’Enginyeria”.

..Uncertainty management
..Investigation & Knwoledge disc

13 When the group first faced the project, only the idea of the project was given and there was no information about how it should be structured. From there, our mentor gave us some explanation about how the Blockchain worked and a more accurate view of how

14 should the invoice factoring process work if it was implemented with Blockchain.

..Idea generation
..Uncertainty management

15 With this knowledge, the team came up with different ideas about the implementation and structure of the project, but there was a lack in depth comprehension of the technology, since none of the members of the team had previously worked with it.

..Experimentation

16 Furthermore, the final application idea was also modified several times, these two problems together, caused that the structure of the project was being modified almost every week, in order to add some features that should be key, but the team did not recognize at first.

17 This was one of biggest problems that the project faced. These several changes, brought many consequences, leading into learning different methods that lately would not be used, wrong implementations, work distribution problems…

..Coordination

18 However, even though this problem might have caused a lot of trouble, it also made the team learn how to work independently and more capable of learning and thinking with new technologies, this helped the team to evolve during the project, improve and

19 understand what teamworks is really about.

..Coordination

20 Teamwork is not working in a group but rather as a group. Giving priority to the team rather than personal preferences. Finding the task that best suits each member considering their background, experience and preference. Managing the whole team to work as one was no easy task.

NETWORKING

21 Another thing the team could have done better was using more the professor figure to get rid of some questions and unclear concepts to speed up the implementation, since at the beginning most of the concepts were vaguely theoretical and were tricky to put into practice.

..Uncertainty management

22 As said before, the main mistake with our project have been the lack of structure or a clear idea of how to implement the project at the start, thus not having a clear idea of how much work something is supposed to be.

..Organization

..Communication

23 As a team, we started slow on some basics due being beginners, since we split the team into two groups that were working on different parts, sometimes there was some lack of horizontal communication and unbalancing workload, what made that on some parts of the project one group having huge amount of work and the other having little amount.

..Coordination

..Uncertainty management

..Self-efficacy

24 Despite of this, the team has managed to be unified and achieve the milestones, even that we have had some extra work. Considering the huge steep learning curve that this project was, we can say that we have successfully implemented the idea even though most of the time at the beginning was spent on the learning phase.

..Coordination

25 After all, considering their background, experience and preference. Managing the whole team to work as one was no easy task.

..Coordination

..Problem solving

..Organization

26 After all, even going through all these problems, in general the team has managed pretty well, we figured out the solution of many problems that came up along the project and also we managed to be able to distribute the load of work adapting to the capacities and the available time of each of the members of the teams. The final result,

..Self-efficacy

27 although can be improved adding some new features, is something we are proud of since we managed to develop a functional system from scratch, from a very abstract idea.

1 **PDP_18_19_Fall_6**

..Uncertainty management
..Self-efficacy

2 As we developed the project, we found ourselves in different complex situations that we had to solve. From the specification table, we can assume that we accomplished most of them.

..Critical thinking

3 Moreover, the specifications that we did not accomplish were because it seems that they are not feasible.

..Problem solving

4 The first thing we can confirm is that we are able to detect if there is powder flowing through the HP 3D printer's tubes. That is, when powder is flowing the capacitance becomes big enough so we can measure the difference. This will allow to detect if the tube is aspiring or not.

..Technical solution/Technology

5 As for measuring the exact quantity of powder that is flowing, we find that harder. The variation of capacitance to detect a difference of 1g/s is to small. We can tell the order of the quantity of powder circulating. That means we can differentiate between 50g/s and 60g/s but not between 50g/s and 51g/s. Nevertheless, we do not discard that it is possible with some improvements.

..Technical solution/Technology

6 Finally, the first calibration of the prototype. The prototype has to be calibrated once before installing it on HP 3D printers. This calibration requires a complex system. We did not have time to develop and create this system. That means that we cannot tell for sure if the measures are completely correct, although from experimental data we think that it is working properly.

..Uncertainty management
..Self-efficacy
..Critical thinking
NETWORKING

7 All in all, the challenge proposed to us was very difficult. We consider that we achieved a good solution. Although there is room from improvement, we consider that our prototype achieves its goal and will be very useful for HP's further investigations.

8 Our journey through this PAE project has been exciting and full of new experiences.

NETWORKING

9 On the one hand, we have had two teaches that have been helping us though all this time.

10 They have been working with us more hours than required. Moreover, they have putted effort into trying to resolve every doubt or problem that we have had.

..Energy

11 On the other hand, we, the 7 members of the group, have putted a lot of effort in this project.

..Coordination
..Organization
..Technical solution/Technolog
NETWORKING
..Uncertainty management

12 We have improved our skills working as a team. We needed to organize and divide the work as we had never done before. We have also acquired new knowledge on electronics and we have learnt how to work for a big company such as HP. We have been able to overcome all the unexpected problems. We have worked efficiently and hard and so we hope the result shows it.

..Energy
..Time management
..Planning

13 Of course, there are always things that could have gone better. The timing has not been our ally. On the one hand, we should improve our punctuality. On the other hand, we should learn to start the tasks with more time in order to avoid last minute changes.

..Energy

14 In a nutshell, we enjoyed doing this project and because of that we have putted a lot of effort.

..Self-awareness for professional

15 We consider the skills that we have learnt very valuable and we are sure they will be useful in our professional lives.

..Technical solution/Technology

..Experimentation

16 On the other hand, we believe that there should be technical improvements. The next steps that we believe should be followed to improve the system would be the following:

17 – Improve the geometry and materials used to obtain a more precise capacity value.

18 – We also believe that a system must be created capable of knowing the amount of powder circulating in order to calibrate the calculated functions.

19 – An improvement to isolate the system, should be, for example, the use of octocouplers to shield external interference.

20 – And finally we believe that wear tests must be carried out in order to prevent failures in the future.

1 PDP_18_19_Fall_7

..Self-efficacy
..Problem solving
..Technical solution/Technology

2 The challenge we faced in this project was remarkable and we as a team are satisfied with the results obtained. A working solution has been delivered and it is tested to perform within the margin of error that we had considered to be acceptable. We are glad to say that the deterministic algorithm, even though it still has plenty of room for improvement, is ready to go into production in Foot Analytics' system.

..Experimentation
..Technical solution/Technolog

3 On top of that, we have explored different ways to approach the problem and learned from each of them. As a high-level summary, we have tried to solve the problem with:

4 1. A deterministic algorithm

5 2. Machine Learning

6 3. Using GSM technology instead of Wi-Fi

..Experimentation
..Experimentation
..Investigation & Knwoledge disc

7 We have had the opportunity to analyze the potential of every line of work and ultimately bet for the one with more chances of success. The deterministic algorithm was the most feasible one and is the only one with a final solution, but we don't leave with our hands empty from our exploration of other possibilities. It has helped us understand the challenge from another point of view and we have gathered a lot of knowledge about these technologies, which we have tried to embody in this final report.

..Self-awareness for profes
..Uncertainty management
..Self-efficacy
..Communication
..Planning

8 On a personal level we have gained a very valuable experience from working on a real-world challenge. This is the biggest project we have faced at the bachelor both in scope and dimensions of the team, and we have learned how to overcome the issues that come from this fact. Planification and fluent communication have been proved to be key aspects.

9 Lastly, we would like to thank Ana and Mª Jose, as well as Akira from Foot Analytics, for their continuous support throughout the project.

..Self-efficacy

10 Overall, we consider the project “Beating MAC Randomization II” to be a success.

..Critical thinking

11 We will start this reflection document talking about what do we think that could have been done better from the side of organizers and lecturers.

..Uncertainty managem
..Communication
..Uncertainty managem
..Organization

12 The biggest complaint we have in this regard is the lack of communication and feeling of improvisation that we have frequently sensed from coordination. It would have been very simple to post in Atenea a calendar with the due dates of all the deliverables and presentations at the very

..Uncertainty management
..Organization

beginning of the semester, instead of informing via email with very little time to react, especially considering that team work requires organization and planification in advance to share the workload equally between team members and tasks require time to maintain a standard of quality.

..Communication
..Coordination

13 As a team, we consider that we have not done things quite right when it comes to communication at the time of writing documentation. We have had some misalignments about the contents of each section, which provoked that it was difficult to craft a coherent final version. Also related with this, we have delivered the final report one day the date agreed with the professors.

..Coordination
..Organization
..Coordination
..Communication
..Organization

14 The performance as a work team has been good. It was the right thing to do to divide the team into 2 subgroups of 3 people. It made the teams more manageable and communication much more fluent. Sometimes overpopulation of teams can be counterproductive, and we have been able to avoid this issue.

1 # PDP_18_19_Fall_8

2 Now that the time for the project development has came to an end, we have to discuss the results and discuss possible improvements.

..Technical solution/Technology

3 Firstly, for the region segmentation using DL, one of the most surprising results was that we could train a Neural Network with synthetic images and it worked well on real images.

..Technical solution/Technology

4 The reason for this might be that the model we chose is very simple and takes into account only low-level information and from a small radius of pixels, due to the convolutional nature of it.

..Technical solution/Technology

5 We also saw that the real images that looked more like the synthetic ones, with regard of the color of the background and tents, were the ones that the model masked better. This is logical from the Machine Learning point of view, and the conclusion we can get is that if we could add more variety to the generation of synthetic images in terms of backgrounds and tents, we could easily get better results on the dataset.

..Technical solution/Technc

..Social impact

..User awareness

6 Also one of the conclusions was that it is possible to get good results on area estimation, using algorithms that require no human interaction at all. This could be very useful if we wanted some automatic real-time tracking of differents places in the world but didn't have the human resources to archive it.

..Technical solution/Technology

7 For region segmentation using color information, we obtained significantly better results when it comes to error. However, color segmentation is a semi-automatic method that requires user intervention, and can't be used in real time. In fact, it can take some minutes until the system can provide results, and the intervention of an experienced user is vital for a good segmentation result in locations that are new or present anomalies.

..Technical solution/Technology

8 It is important to mention that both approaches have been developed with a very limited number of satellite images, if a bigger database was available, we are certain that better segmentation results could be achieved. We think that the Deep Learning segmentation would specially improve in a context where many satellite images from refugee camps are used to train the system.

9 Clouds:

..Problem solving

..Technical solution/Technolog

10 Our objective was study the possibility to remove clouds from an image. After all the research, and a lot of coding, we think that is possible to recycle the satellite images and obtain a new image without clouds. However, is necessary to have an old picture of the zone in a cloudless day. The result would be an image with a new information, the part without clouds, and old information.

..Experimentation

..Technical solution/Technolog

11 Also, we studied others possibilities, like use a band that reduce the clouds (microwave band). But after all, we think that the method used is the optimal in this case.

12 The cloud removing is not easy, but is possible under some conditions.

..Critical thinking

13 Further improvements can be done to the cloud part of the process, for example, if we had a routine downloading of images from the same place, we could keep a cloudless free image updated the most. Meaning keeping the most recent cloudless pixels from the recent downloaded image and discarding the ones with clouds and the older ones.

14 There could also be an improvement if there was a direct

downloading of the imagery (something that can be down but only under a license).

..Coordination
..Coordination
..Communication

15 Over these three months, we have been trying to work together to obtain the desired product. The general work environment has been favorable. We have been very supportive to each other and devoted to the task each member had. We didn't have any misunderstanding due to communication because we would do a group meeting every class to evaluate the evolution of the project and the tasks each member was tackling.

..Organization
..Planning

16 The only organizational challenge we have came across is that we didn't structure sufficiently the work. We were working constantly without having previously defined partial milestones and it has resulted in a final sprint in terms of working hours to achieve final results according to the subject deliverable times.

17 The fact is that this could have been dealt with when writing the mentioned deliverables, but another mistake we faced is we didn't take enough seriously the content that we wrote, we saw it as a deliverable more than a necessary organizational document. This is the part that we would change and that we could have benefited from having a better result.

..Organization

18 The task distribution was something we successfully achieved, since everyone has been kept busy but not overflowed with work during the majority of the term. The tasks were equitatively distributed.

..Self-efficacy

19 All in all, we are satisfied with how the team has developed the project. It has been an enriching experience for all the members.

1 **PDP_18_19_Fall_9**

..Problem solving

2 To sum up the project, a program that runs perfectly from a server has been written in order to be accessible and helpful to use for all kinds of users around the world.

..Technical solution/Technology

3 The program itself is built into two main parts: localization and classification.

..Technical solution/Technology

4 The first part of the program applied to the input image is the classification. This part currently divides the input image into three classes: Pneumonia ill, Healthy or Other Diseases. This is due to the fact that the database that we have trained the system with is not big enough to have a more accurate and complete classification. If a bigger database would be handled with enough images of each type of pneumonia and each type of the other lung diseases labelled, a complete diagnostic tool could be done.

..Technical solution/Technolog
..User awareness
..Technical solution/Technology
..User awareness

5 After that, if the image is detected as pneumonia ill, it goes through the localization CNN. This part of the project has been changed to fit the necessities the doctors from Sant Joan de Déu asked us for. Instead of prioritizing the level of similarity between the bounding boxes indicated in the images and the predicted ones, the number of bounding boxes detecting possible parts of the chest x-ray that may have pneumonia has been increased in order not to lose any possibility of pneumonia ill images. It is preferable to detect pneumonia when there is not than detect an image as healthy and after that be too late to treat the patient.

..Business sense

6 Taking this into account, our software fits and accomplishes the necessities of the population of a software of this kind with the resources we had worked with and we have demonstrated the viability of a company commercializing this kind of software as well as the possibility of enlargements that could be done to it.

..Social impact

7 To make our code accessible to everyone who would like to improve it and be one step nearer to its final implementation in the real life we have uploaded it to GitHub web in the next link:

8 HYPERLINK "https://github.com/brunoibez/PneumoniaDetector" https://github.com/brunoibez/PneumoniaDetector

9 In this last section of the final report of our project, there is a reflection of how this four-month project has been dealing with the organization of the team.

..Organization
..Organization

10 When the assigned professor, José Adrián Fonollosa, explained with more details the scope of our project, we automatically saw that there was a clear division of it into two parts, as explained in the whole document. So, what we first did was to split the team into two sub-teams. Here there was the first organization problem, as we thought developing an interface was easy and that we could leave it for the last weeks, but finally it appeared to be more difficult, so a proper initial sub-division would have been three sub-teams: Classification, Localization and Interface.

..Organization ..Coordination ..Leadership/Initiative ..Organization ..Coordination ..Organization

11 What we also found out later was that sub-teams of 4 members were not functional, as there were many people, and only a few from each sub-team were really working. This problem should have been treated not only by the Project Leader but also by the team members, as the ones who had no work should have said something or asked for it. Despite those organization problems, all the work was done in time and, in terms of the project itself, the involved team members did a great job.

..Organization ..Communication

12 Weekly meetings were very helpful to discuss the incoming problems and the different ways to solve them, and to keep everyone, including the professor, informed on how the project was going on, what had already been done and what remained to be done.

..Organization

13 As the project was going on well, the project leader had to focus more on the documentation part, as some team members did not pay enough attention to the deliverables and she had to organize the work that had to be done by each team member and ensure everything was done by the deadline.

..Self-efficacy ..Self-efficacy ..Self-efficacy ..Problem solving ..Self-efficacy ..User awareness ..Social impact

14 To sum up this reflection on the project, we would like to show our great satisfaction with the final result. We started from scratch, without any knowledge on deep learning software applications and we have built up a program that accomplished all the given specifications. We think this is a very complete project as we have worked hard with the diagnosing program itself, but we have also worked to build a useful and user-friendly interface even though none of us had deep studies in telematics. We are proud of the project we have built up and we expect it will be improved so it will finally be used by doctors in real life and be useful for these medical workers and general users that work in underdeveloped countries or in the countryside to help decrease the deaths of pneumonia of the risk groups of population (kids under 5 years and adults over 65 years old) all around the world.

1 PDP_18_19_Fall_10

..Self-awareness for professio
..Coordination

2 In this project we had to develop two application for a point of sale, one to management the tips and their statistics, and the other to split bill. The results obtained in relation to the objectives of our project, which are the consolidation and expansion of the contents of the previous subjects and the acquisition of high-level competences, allow us to conclude that the team has performed remarkably well.

..Uncertainty management
..Organization
..Uncertainty management

3 During the course we have had to face multiple challenges in the different phases of the project. Despite this, our responsiveness has been appropriate because we have worked with agile methodology. Although this has not been enough, we have also had to apply all our knowledge acquired in the bachelor's and learn from new, because we have had to work on a development scenario unknown to us.

..Uncertainty management
..Time management
..Organization
..Planning

4 However, we had a lot of limitations at the beginning, especially due to requirements that were not very clear, and we were not able to dedicate all the time we wanted to the implementation of the applications. On the other hand, it has allowed us to know in more detail all the phases of a complete project; from the conception and design of an application as user friendly as possible, to the implementation of it, testing and documentation.

NETWORKING

5 Thanks to the constant meetings with Comercia, they have been conscious of all the problems that we had, which has been a quite an experience for them to the future projects with the university. The support with our problems by Comercia has been notable.

..Technical solution/Technology
..Coordination
..Organization
..Self-awareness for professional

6 It has been a project of programming, and it allow us to learn new environments and languages. The result is satisfactory and Comercia knows more deeply the next steps to complete it. In relation to the work team, the workplace has been excellent, all members have participated in the documentation and implementation. In addition, we have distributed the work very well according to the availability of each one. All these aspects have allowed us to know better the professional life of a software development.

7 **- Things that could have been done better by the organizers/ lecturers**

..Uncertainty management

8 From the point of view of the organization of the project, we believe that it could have been explained more clearly from the beginning, all the tasks to be carried out with their corresponding deadlines.

..Planning
..Organization

9 This change, could help in order to have a better organization and optimization of time since in some moments of the course we have had some inconvenience to organize the whole team to prepare documents and presentations in less than a week from the notification of its deadline, causing a break in the flow of tasks provided in our Sprints with Agile methodology.

10 Regarding to the company, Comercia provided us the initial SDK

with a certain delay which caused us to lose the first month of the course without material/tasks to do. Moreover, our project has been limited during the process as Commercial hasn't provided the POS terminals that we were told at the beginning of the project.

11 **- Things that could have been done better by the team**

..Organization
..Planning

12 At the beginning of the course we introduced the Agile methodology in order to split the tasks with the aim to each member of the team could do whatever topic task required. Unfortunately, we could not achieve it as finally we have specialized by topic, presentation, documents or app development.
13 Looking forward to future projects we would like to be able to follow the main objectives.

14 **- Performance as a work team**

..Communication
..Organization

15 Despite the facts mentioned before, on the whole, we consider that we had a great connection between all the members of the team that allowed us an easy communication. However, an issue to consider would be the time lost on irrelevant facts of the implementation that didn’t required as much time as we did.
16 This situation caused that the final sprint became the most tough because has been during the final term exams and we had to dedicate much more effort to fulfil the initial expectations.

1 PDP_18-19_Spring_1

2

..Organization
..Technical solution/Technolog

3 The aim of the project was to develop a fully functional Transport Stream searcher, which could work with a database provided by Sony, using its criteria. To do this on time, the team has been organized in different sub-teams and the time planning was done in a set of “waves”. As our organization model has been like that, the group has also learnt how to integrate a modular software into a big main one.

..Technical solution/Technology

4 When the integration has finished, it has been developed some more functionalities, such as the command line interface of the searcher/input module and the expansion of the searchable features.

..Technical solution/Technology
..Communication
..Communication

5 Thus has been an interdisciplinary project, and by that, it means that all the team had to face a lot of different things, creating a database by scratch, using Python3 to develop a searcher which uses the database model, learn how to work with Transport Stream files and parse XML’s files among other things. However, the most important issue that we had was our lack of communication, which was crucial due to the number of people and teams of our group. Needless to say that, if we hadn't learnt how to communicate better, we would not have finished this project on time.

..Technical solution/Technology

6 Talking about the project itself, the project’s input part is always the same, but in terms of the output module, it has been implemented two modules, the search by string and the search at the database. Looking at the computational costs explained before, it can be concluded that searching at the database is much more efficient than searching by string, so the database implementation was worth to work in.

..Energy

7 The project has become what we expected, and it's the result of hundreds of hours, questions, doubts, teachers, ourselves and obviously Sony's representative, who has been guiding us during its development.

..Energy
..Organization

8 From the beginning, the whole team and the lecturers knew that it was an ambitious project. Since the first day, all the team has been working hard and giving their best to make the project succeed. Every single decision has been debated and finally made with internal consensus and the approval of the lecturers: from the division and organization of the team in different subteams, to the littlest issue of the implementation.

NETWORKING
..Energy

9 During the project development, we had to change and add several features of the project due to new requirements of Sony, but the team managed to do it efficiently. As the work was well organized, we could afford implementing all that new requirements. We also tried to go a bit further in the project and implemented some features that weren’t asked but made the project better.

..Communication
..Organization

10 As there where 4 different subteams, sometimes we realized that there was a little lack of communication between them.

..Communication
..Organization

Nevertheless, having noticed that, we fixed it by making weekly general meetings and extra meetings, when needed, where each subteam exposed what were they doing and how were they doing it.

..Energy
..Self-efficacy

11 To sum up, the team did a great job and every single engineer worked hard, so maybe things could be done different but the team did their best.

1 # PDP_18-19_Spring_2

2 After developing such a big project, it is really important to draw conclusions about it.

3 First of all, we have to look back at the objective we had at the beginning, and determine whether we accomplished it or not. The main goal was to create a VR experience that simulates dyslexia in order to make people who does not suffer from dyslexia empathize with people that do. Although there are lots of improvements that can be done, we consider that we have successfully accomplished the objective.

..Problem solving
..Critical thinking
..Self-efficacy

4 To accomplish it, it was really important to organize a big team of 12 people. Doing a deep research about the subject we were treating was fundamental. As none of us had a deep knowledge about dyslexia, we decided that the whole team should be involved in this research part. This was definitely a great decision because it helped us a lot when developing the project.

..Organization
..Investigation & Knwoledg
..Investigation & Knwoledg
..Uncertainty management

5 Teamwork was also a key to this project. Everybody knowing what to do was essential in order to optimize the time assigned to this project. Not only the teamwork was essential, but also the great working atmosphere we had every day.

..Coordination

6 This project also helped us understand how a “real project” comes to life, and all the steps the team has to follow from the first thought or idea to the final product. Each step, from research, ideation or development, to the testing, is essential.

..Self-awareness for profes
..Organization
..Planning

7 In particular, we learned a lot about the Agile methodology and how the Developing-Testing iteration works, and how important it is to develop a product that really fits the needs of the user or client.

..Experimentation
..User awareness

8 In conclusion, this project has been a great source of learning, and has taught us to look beyond the technical aspects of a project and give importance to other parts of a project. We are very proud with the final result and with the whole process we have followed to reach it.

..Self-awareness for professional
..Self-efficacy

9 In this last point of the final report, we will discuss and explain some decision that could have been done better by the team and by the organizers of the subject.

10 When the team faced the project, there was a main goal, to make people to empathize with dyslexic people. The tool used was also mandatory, Virtual Reality, but there were neither any instructions or knowledge about how to do it. The company suggested us to use the software Unity, which is a very good tool for developing Virtual Reality. No one of the team was familiarized with this software, so we started to learn how to work with it. However, our first steps were to learn and understand what dyslexia is and what does it mean to have it. This lack of knowledge was fixed by doing a research and asking people with

..Uncertainty management
..Technical solution/Technolog
..Investigation & Knwoledge disc

..Investigation & Knwoledge disc

experience on this topic.

..Organization
..Communication
..Energy

11 The organization of the team has been easier than we thought at the beginning, considering that we were a team of 12 people. Communication, dedication and implication have been constant and crucial for the development of the project. However, the distribution has been changed and there were different points of view until we made the ideation phase. At this point everyone knew what they had to do.

..Organization

12 The structure was quite horizontal, all the proposals and developments went through the team leader who worked as a link between the Unity and design teams, with the teachers and with the company. As it was an open project, there was the possibility that each one could work in the desired part, more technic as it was unity team or more creative as it was the design team. Finally, we were 6 people in each team.

..Coordination
..Idea generation

13 As a team, we have evolved a lot since the beginning, growing in confidence and with the desire to work. Moreover, with the dynamics of Everis, we have seen how to face a project, how to respect diversity of ideas and to make the best decision for the team.

..Technical solution/Technolog
..Critical thinking

14 There are many decisions that could have been better in the technical part. It is crucial to understand that Unity has been created for the development of videogames and that means that the aim is audiovisual contents with user interaction and, in our case, it is also immersive in virtual reality and available for iOS and Android operatives system. As a consequence, for a single cube, the amount of scripts created by Unity is huge.

..Communication

15 Also, team design could have made better decision. Those decisions that we would change if we could start again it would be to have a better task's control. At the end of ideation phase and the beginning of construction there were a huge amount of material like images that had to be transfer from the design team to unity team. For that reason, we should have had a better communication between working groups.

..Technical solution/Technology

16 Furthermore, our project is not as efficient as it could be because we priorizate to have a good functionality from efficiency. Therefore, when something worked properly we continued with another part of the project . After the product result, we think that we could have invested more time researching an efficient way to do some scenes and automations, as some processes are slow and repetitive.

..Technical solution/Technology

17 In addition, we started using a merge tool after a while of developing the project. The merge tool used was GitLab, which none of us has used before, and when we began to use it, the project was already huge. Also, the adaptive process of using a new tool was slower and more difficult than if we started using it from scratch.

18 On the other hand, we think that the organizers have done a very good job and helped us a lot, but they can improve some things. This work has been developed for the subject "Projecte Avançat d'Enginyeria"

..Planning

and, this is the biggest project that most of us have faced ever. During this four months, we learned a lot not only Unity but also how to face a project from the beginning. However, even though we consider that documentation is a vital part of a project, it would have helped us if the documentation requirements were more flexible depending on the project. In our case, we had a broad topic and we could face it with multiple solutions. Documentation could be a useful tool which might help us to develop the discovery and ideation phases.

19 The lectures were great because provided us extra knowledge about different parts of a project. As we made minutes of the lectures, the information given at those classes are available for anyone of us.

..Self-efficacy

20 To sum up, even though there are a lot of things that could have been done better from everyone, we think we did a great work and achieved the challenge and the school gave us the tools to made it.

1 **PDP_18-19_Spring_3**

..Experimentation
..Technical solution/Technolog

2 In this project five different methods were tested. As explained before, we have 3 different prototypes for hardware, MATLAB scripts as a support and a way to gather relevant results to improve hardware prototypes, and the deep neural network, which gave us the best expectations at the beginning and the best results at the end.

..Technical solution/Technolog
..Experimentation

3 Detection problem via hardware was tested with some files of the database generated by deep learning group for species recognition.

..Experimentation
..Technical solution/Technolog

4 MATLAB scripts method was tested with the complete database for species recognition and also with one specific database mixing 2 databases from DCASE Challenge 2018 (warblrb10k & BirdBox20k). This mix was done in order to balance the number of bird files and non-bird files.

..Technical solution/Technolog
..Experimentation

5 Last but not least, deep neural network method, tested with all DCASE Challenge public databases in order to train, evaluate and test. As mentioned before deep learning group made as well a deep neural network for species recognition with 5 specific species from Catalonia. To test species recognition they generated a database that at the end the whole team used to test to give the final results.

..Experimentation
..Technical solution/Technolog

6 The results obtained for the 3 hardware prototypes were as expected: the best results were obtained with the dsPIC, which had an accuracy rate of 95%. This means that out of the 20 samples, only one, that was actually a bird, was detected as not a bird. In second position, the Arduino MKRZero obtained a result of 90 % of accuracy. And finally, the Arduino DUE obtained an 85% of accuracy.

..Technical solution/Technolog
..Experimentation

7 For the deep neural network, the best results obtained for bird detection were 83% with DCASE Challenge 2018 warblrb10k database. And as for the species recognition, a confidence of 74.49% was obtained for well predicted samples and 47.07% for wrongly predicted ones. As mentioned above, two of the recognizable species caused confusion since they were sometimes not well predicted, although with more samples and more time, this could be solved.

8 At the last part of this document we will analyze our performance as a team and as an individual: what we learned, what should be done when something failed and what we have achieved.

..Coordination
..Organization
..Planning
..Communication
..Organization

9 Eleven members team is not something easy to deal with. Too much people, if not well organized, will not give any results because people will wait until others do something. We solved this lack of communication and planning one month after we started the project, at this point we had no idea of what others had been doing. First of all we had a meeting to talk about everything we had done and how it performed and what we could do to start having a closed idea for our project.

..Planning
..Problem solving

10 Once we had a plan we started talking about improvements and features that could be easily tested on every hardware prototype.

..Technical solution/Technc
NETWORKING
..Technical solution/Technc

Also, on the second meeting with the company, integration problem and communication problem appeared, we had not thought about how we will communicate everything. At the end we could not give a closed solution, just a patch that processes data before the deep neural network, but input is made manually.

..Technical solution/Technology

11 Something we did no thought about was taking some time to know how databases for testing were. For example, how many samples for training, evaluate and test were needed. Moreover, with detection problem, the most relevant results are obtained with a balanced database of bird non-bird files, something we did not know before the second month of the project. Since then, we spent some time we did not have planned for balancing databases and also dividing them into: training set, evaluation set, and test.

..Coordination
..Coordination

12 Talking about the team, we observed a high disconnection between the people, and without a good connection you cannot do so much. Not all teams are made to work together. In our team, there were some divisions where people had much more confidence and connection to work than with others, this is a problem that appears sometimes in big groups that not all have the same thoughts.

..Self-efficacy
..Critical thinking

13 At the end of the course we obtained results good enough, not as expected, but we had a lot of problems in the middle.

Annex E – INCODE responses

Individual																								Interpersonal																Networking									
I present ideas that are suitable for the task - 1		I present creative ideas - 2		I present new ways to implement ideas - 3		I evaluate the advantages and disadvantages of actions - 4		I identify relationships among different components of the task - 5		I face the task from different points of view - 6		I use available resources ingeniously - 7		I foresee how events will develop - 8		I show enthusiasm - 9		I persistently pursue the goals - 10		I take daring yet reasonable risks -11		I orient the task towards the target - 12		I transmit ideas effectively - 13		I listen to teammates - 14		I establish constructive group relationships through dialogue - 15		I collaborate actively - 16		I contribute to group functioning - 17		I take initiatives - 18		I drive others to act - 19		I face conflicts with flexibility to reach agreements - 20		I apply ethical values - 21		I take into account the implications of the task for society - 22		I am able to work in multidisciplinary environments - 23		I am able to work in multicultural environments - 24		I use networking contacts to reach goals - 25	
CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP	CBI	PDP
4,31	**4,12**	**3,75**	**3,86**	**4,13**	**3,82**	**4,53**	**4,08**	**4,16**	**3,92**	**4,09**	**4,00**	**3,94**	**3,63**	**3,72**	**3,69**	**4,09**	**4,16**	**4,41**	**4,12**	**3,91**	**3,45**	**4,22**	**4,12**	**3,59**	**3,80**	**4,34**	**4,43**	**4,03**	**4,22**	**4,13**	**4,29**	**4,25**	**4,24**	**###**	**4,04**	**3,78**	**3,71**	**3,94**	**4,02**	**4,00**	**4,29**	**3,88**	**3,88**	**4,53**	**4,39**	**4,56**	**4,57**	**3,59**	**3,80**
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Table 53. INCODE Barometer Rubric 5 responses CBI and PDP

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