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. The main goal of this paper is not to describe the CBI course but to compare the Design Thinking approach with the analytical design currently employed in the engineering school involved in this course using the CBI course as a study case. 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 the approach used in the CBI program.

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 main goal of this paper is not to describe the CBI course in detail but to use it as study case to compare the Design Thinking approach with the analytical design currently employed in the engineering school involved in this course. The learning outcomes of the engineering students, compared with those obtained in the regular design-build 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).

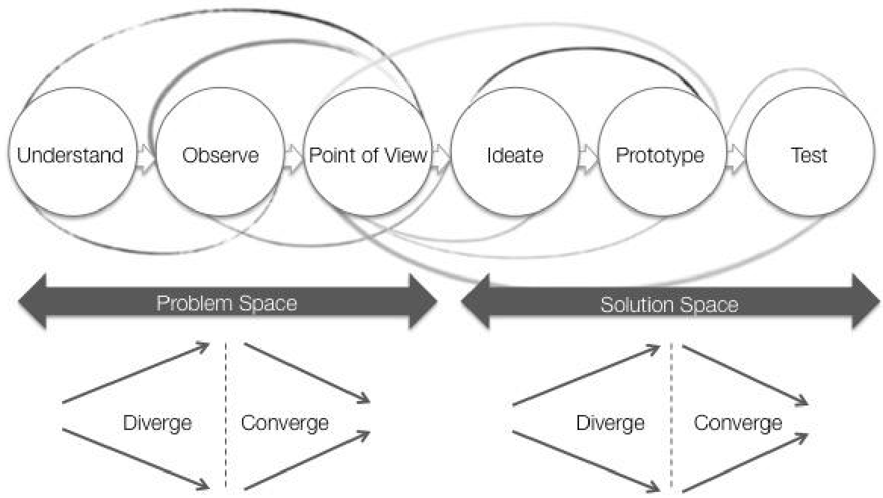

Figure 1. *Steps in a Design Thinking process (adapted from Ratcliffe, 2009)*

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.

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.

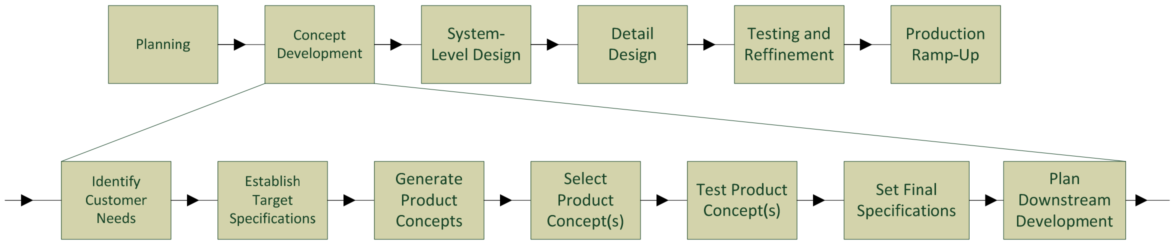

Figure 2. *Phases of product design and detailed phases of Concept Development. Adapted from* Ulrich-Eppinger (2008)

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)

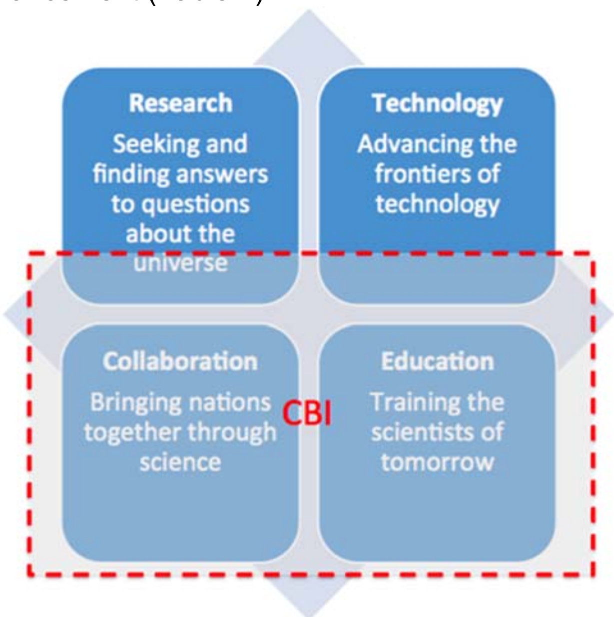

Figure 3. *CBI's focus within the mission of CERN (source: CERN website)*

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 reports of the projects performed the current academic year will be soon available in the same site. This last fall semester, 19 students (5 from ESADE, 6 from IED and 8 from UPC) coming from 9 different countries, have been distributed in four teams to face four challenges: “European Labour Mobility”, “Food Safety in Home Delivery”, “Creating a Literate World” and “Water Safety”. The teams that carried out the first two challenges joined with two four-people teams from UNIMORE, in Reggio Emilia, Italy. Because of this the course was called CBI@ Mediterranean. These two first challenges were partially specified and sponsored by companies while the other two were defined by the teaching team. The schedule of the course is shown in table 3:

Table 3. Schedule of the 2015 edition of CBI course

Week	Location	Phase	Seminars	Deliverables
1	ESADE	Research	Introducing CBI challenges. Design Thinking methodology. Project Management approaches	CERN Workplan
2	Idea Square	Research	Understanding CERN. CERN technology macro domains. Case presentations	Research plan for 3 weeks. 1st Checkpoint presentation
3	UPC	Research	Design&user research. Trends research and analysis	
4		Research	Intellectual property and patents	Research results
5		Research/ Ideation	Ideation process Conceptualization / Moodboards	Preliminary list of relevant technologies and contacts at CERN
6		Research/ Ideation	Lego Serious Play	3 rough prototypes
7	Idea Square	Ideation/ Proto&Test	Concept testing & validation. User tests	Mid-term presentations
8	UPC	Ideation/ Proto&Test	Business Models and experimentation	
9		Ideation/ Proto&Test	Distribution strategies for entrepreneurs	First draft of the business plans & uncertainties identified. Results from testing
10		Proto&Test/ Convergence	Financial Plan: How much money is needed?	
11		Convergence /Design	Funding the new venture: How do you get the money?	Financial Plan
12		Design	Hardware and software prototyping. Storytelling & Visual communication	Work and research plan for CERN
13	Idea Square	Design		
14		Design/ Presentation		Final presentation
15	UPC	Final deliverables		Final reports and models, project video, personal reflection

The students from the three institutions in Barcelona joined a first full-time week at eGarage, a space for co-creation located in ESADE, then a second week at IdeaSquare at CERN, followed by a period of five weeks in which the teams met a whole day per week at Espai Emprèn, a co-creation space located at UPC campus. During this weekly day, the students followed a series of seminars and workshops (1-2 h per week), presented the deliverables of the previous week and worked on the successive phases of their projects. Then the students stayed along a week at IdeaSquare where they meet CERN scientists and continued with the ideation phase. After that, five more weekly days at UPC, completing the solution convergence and starting the final prototype design, which was completed and integrated during the last visit to IdeaSquare (10 days), which finished with the final presentation in front of the IdeaSquare community, CERN scientists and invited stakeholders. Student's assessment is based on the evaluation of the team performance and the result of the project (relevance, originality, impact): 50%, the individual performance (the process and quality of work done, the application and adaptation of specific prior knowledge in a multidisciplinary project, the adaptation to a multidisciplinary environment): 30% and peer evaluation through a rubric: 20%.

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 consultants 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).
- In capstone and other design-build projects following the classical approach, the need of having all sub-systems working and of integrating them before the product delivery adds a real need of solving practical issues, dealing with unexpected problems (technical issues, delivery delays, discontinued parts, …) and of negotiating the solutions into the team. On the other hand, the concept statement is usually set from the beginning and the requirements and specifications are frozen in the first weeks. In opposition, in CBI projects, although a given technical development level of the final prototype is required to provide a proof of concept, the relevance and impact of chosen needs and solutions are more critical and most conflicts and issues appear in needfinding and ideation phases, when validating chosen alternatives with stakeholders.
- Related with the previous paragraph, the planning and documentation needs are different in both cases. In the Telecom-BCN capstone projects, a strict planning and documentation method is followed, including risk analysis and contingency plans to cope with delays and incidents and to ensure the traceability of the design process. The creative phases of the CBI projects however, need a more dynamic approach and the documentation is intended as an aid for understanding the different steps and for communication with stakeholders. Videos and other visual representations often substitute the formal reports. Final reports and presentations also enhance the technical achievements or the user/market orientation in the two approaches.
- 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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