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Addressing Long-Term Challenges In Energy For Sustainable Futures By Applying Moonshot Thinking

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ABSTRACT

The rapid and exponential changes in our world require the education of engineers who can develop solutions to future and long-term challenges such as climate change. Exploration and innovation methodologies such as Futures Thinking and Moonshot Thinking have the potential to equip engineering students with useful tools and skills to build sustainable futures. To this end, the InnoEnergy MSc Energy for Smart Cities programme at BarcelonaTech (UPC) has developed a challenge-based learning (CBL) course that applies moonshot thinking to tackle major energy problems. This paper presents the methodology refined over three years of implementing the CBL course with second-year Masters's students in Energy Engineering. The course begins by constructing a narrative working future using exploratory tools from the Futures Thinking methodology. Breakthrough technologies are introduced, and their disruptive potential is analysed. Students then define a long-term sustainability and energy problem and use various ideation methodologies to develop a solution. Using technologies such as 3D printing, artificial intelligence and open-source electronic prototyping platforms such as Arduino, they build a minimum viable product (MVP) and develop a business model. Finally, using an agile approach, students must design future iterations and analyse the potential exploitation of their solution. This subject equips students with the necessary skills to address complex energy and sustainability challenges, and the course has proven effective in preparing students to apply their knowledge in practical, real-world settings.

1 INTRODUCTION

How do we train students for jobs that have not yet been created, to use technologies that have not yet been invented, or to solve problems that we cannot yet imagine? These are some of the concerns raised by international organisations such as the Organisation for Economic Co-operation and Development (OECD) [1] when examining the future of education. Others, such as UNESCO's International Commission on the Future of Education [2], point out that the key is to advocate curricula that develop creativity, engagement and a broad range of skills through community-engaged, project-based pedagogies.

In 2020, the Moonshot pilot was created by the Universitat Politècnica de Catalunya-Barcelona Tech (UPC) as part of the MSc Energy for Smart Cities programme, in collaboration with Fab Lab Barcelona and with the support of the European EIT organisation InnoEnergy, as a response to these new educational challenges.

The moonshot took humankind into space and allowed us to leave a footprint on the moon. Years later, the concept of moonshot thinking has evolved into a way of tackling big challenges, including climate change, by coming up with unconventional ideas and using disruptive technologies to find solutions. The key principle of the course is that it is often easier to make something 10x better through radical change than it is to make it 10% better through incremental improvement. Students must validate their most innovative ideas under tight deadlines and high targets to achieve this goal. They are required to test prototypes with the intention of failing and then learn from that failure to make the next prototype much better while maintaining an ethical focus on the environmental and social impact of their ideas and projects.

2 THE MOONSHOT THINKING PROGRAM AT BARCELONATECH-UPC

The main objective of this course is for the student to go through the process of moonshot thinking and to learn about the different stages of this methodology. Students are expected to learn about the methodology, develop key skills in applying the methodology, and become autonomous decision-makers.

This course has been implemented as a pilot project exclusively for MSc Innoenergy students during the three years from 2020 to 2023. It is a 15 ECTS semester-based course and consists of blocks, as shown in Fig. 1.

The course is divided into eight blocks, as shown in Figure 1. The grey blocks represent the general topics (Introduction and Presentation). The blue blocks cover the brain activities (Futures Thinking, Problem Analysis, Ideation and Solution Development, and Exploitation and Business Development), while the green blocks address the hands-on activities (TAUM and Sensors and Product Prototyping). The course starts with a block on introducing the methodology of moonshot thinking and its basic philosophy. Examples will be given, and references to existing projects (including those in the energy sector) will be discussed.

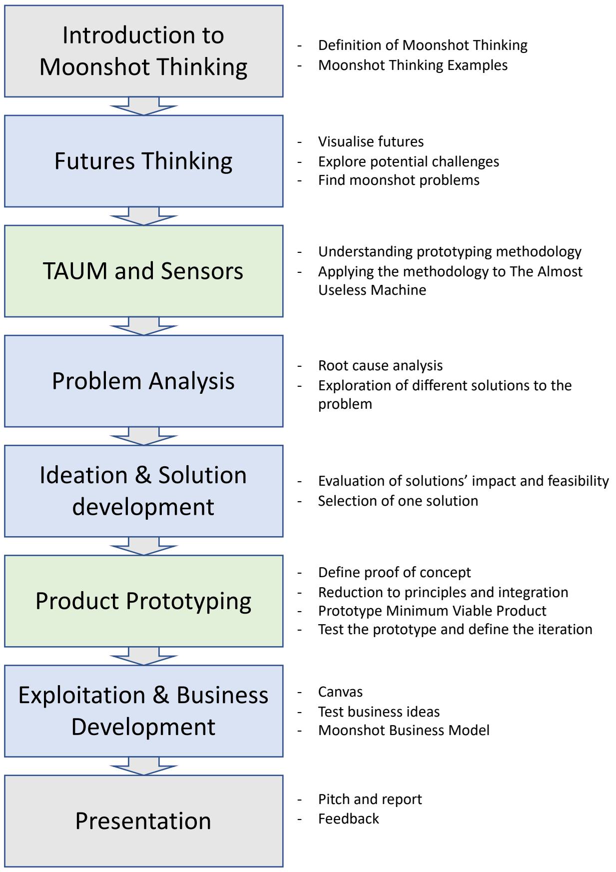

Figure 1: Overall methodology at the Innoenergy UPC Moonshot Thinking Course.

The brain activities start with *Futures Thinking* block. Concepts such as different futures, weak signals, moonshots in the electricity grid, the Sustainable Development Goals, exponential technologies, megatrends and activities such as describing the future or asking "how could we..." questions were carried out. This phase provides students with valuable insights into the major future issues facing the energy sector, particularly in the decade 2030 to 2040. Students can choose a specific topic to work on in groups of 2 to 4 students.

The hands-on activities start with an introductory block on rapid prototyping technologies, through a practical session on the prototyping methodology, but not applied to the specific idea (TAUM-The Almost Useless Machine). The outcome of this block is solely to provide the student with knowledge and skills in rapid prototyping technology and its practical implementation. The Problem Analysis block devotes activities to the analysis of selected scenarios from the Futures Thinking, the identification of problems, the analysis of the root cause of the problem and the exploration of different solutions to the problem. The next block is dedicated to the Ideation process, where Design Thinking methods are used to define disruptive ideas without putting the students' creativity at risk. The Product Prototyping block is dedicated to prototyping a proof of concept of the specific idea from the ideation process, evaluating the design, and testing the developed prototype and iteration. The following block is related to exploitation and business development and explores the future potential of the disruptive concept and the business dimension. The outcome of this block is the ability of students to transform disruptive ideas into business opportunities using a methodical approach.

The course concludes with presenting the project to a panel, including external judges. Students present a pitch and report on the moonshot project, including the process steps. Special attention is given to the integration of different steps and future work. The course assessment is based on the deliverables, the final presentation and the student's work and impact throughout the semester. The pilot was carried out over three years with the participation of 17 students, almost evenly distributed over the three years and balanced in terms of gender.

3 FUTURES THINKING

Engineering degree programmes provide students with a comprehensive education in fundamental principles and theories, enabling them to develop the knowledge and skills necessary to apply advanced technologies and solve complex real-world problems. Most challenge-based learning (CBL) subjects in these programmes take a present-forward approach, addressing current challenges to develop robust and sustainable solutions. However, the Moonshot Project takes a reverse methodology, imagining a possible future and developing solutions backwards to the present, resulting in long-term and innovative solutions fostered by exponential technologies.

Futures thinking, or foresight, equips students with skills and resources to approach problem-solving strategically. While controlling or predicting the future is limited, conceptualising the future influences present attitudes, behaviours, and decision-making. Futures thinking ensures that breakthrough ideas pursued in Moonshot thinking are grounded in reality and have a practical path forward.

Futures thinking explores the possibilities, opportunities and risks that may arise in some years. Multiple potential scenarios exist, challenging assumptions and expanding perspectives while uncovering trends and signals that inform our understanding of how the future may unfold [3].

Alternative futures can be categorised as possible or probable based on the level of uncertainty, calling preferable futures those that align with normative value judgments. Recent developments in foresight studies have expanded this taxonomy to include plausible and preposterous futures and concepts like wild cards and black swans. Figure 2 illustrates the Plausibility Cone, which provides a framework for understanding how these different futures fit together [4, 5, 6, 7].

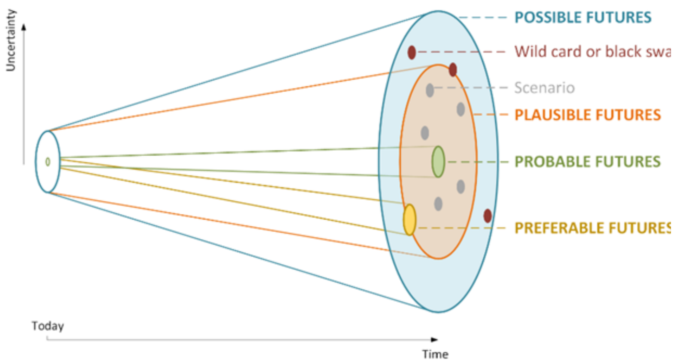

Figure 2 Futures Cone followed in the Moonshot Thinking Course.

The exploration of futures follows an inside-out approach, starting with probable futures by exploring current megatrends and past events. To analyse plausible futures, the students develop scenarios based on their understanding of how the world works. The spectrum is broadened with possible futures by introducing wild cards or black swans, seemingly improbable events with disruptive impacts. Finally, the students define their preferable future and work backwards to the present, identifying areas requiring disruptive innovation. The backcasting methodology helps align long-term visions with short-term actions, enabling the development of practical and actionable solutions. [7, 9].

The learning block incorporates resources from the Joint Research Center of the European Commission. The exploratory workshop "Working with megatrends" is conducted to explore probable futures, and the role-play simulation tool called "The Scenario Exploration System (SES)" is used to delve into plausible futures in sustainable cities. These activities enhance understanding of future energy systems and cities, fostering creative thinking and innovative problem-solving skills [9, 10].

4 IDEATION: FROM THEORY TO PRACTICE

Google X [11] is one of the organisations that has launched more disruptive projects of diverse nature in the previous years and has conceptualised the term “*Moonshot*”, consisting basically of the intersection between three concepts: (1) a huge problem in the world that affects millions or billions of people; (2) a radical, sci-fi-sounding solution that may seem impossible today; and (3) a technology breakthrough that gives us a glimmer of hope that the solution could be possible in the next 5-10 years.

The case of Henry Ford disrupting mobility, from horses to cars, illustrates the intersection: (1) the huge problem was related to the feeding of horses and the accumulation of their faeces on streets [12], (2) the radical solution was the replacement of animal traction and (3) the breakthrough technologies were the gasoline motor and the assembly line manufacturing method that allowed replicability (related to the concept of “abundance” in [13]). The etymological definition of the verb “*to disrupt*” can be defined as “*to break something into pieces*” [14]. In this example, Henry Ford disrupted “mobility” by replacing one of the elements involved in mobility:

animal traction. This innovation opened new markets and expanded the concept of mobility, such as motorbikes, trucks, aviation, etc., reshaping the entire ecosystem in a reminiscence of the concept of "*creative destruction*" [15].

On the one hand, today, the convergence and democratisation of technologies [16] make it easier for small players to develop disruptive products. On the other hand, large incumbents are more aware of the potential risks derived from disruptive innovations. Therefore, they actively search for new entrants that could challenge their dominant market position and absorb them before becoming outcompeted.

The practice of Moonshots is not straightforward. In the "Futures Thinking" sessions, the students devise a set of long-term scenarios, pointing out the direction of their project and the goals to pursue. The underlying questions of "How *to get there?*" or "How *might we…?*" aim to trigger new ideas of solutions and applications.

We surveyed students to discover their interests and ensure group alignment. Moreover, we requested that students write down their vision as a long paragraph since writing has proven to be an efficient tool for distilling and organising thoughts. Furthermore, we have scheduled a set of deliverables after the major milestones so that students find the time to document and report their progress. This way of doing this makes it easy for students to write the final report.

In this 2022-23 edition, we have dedicated more time to the ideation process, aiming that the students would develop high-potential ideas and would engage more in the project. Our expectations were met mainly but at the cost of students having limited fluency and clarity in pitching their idea to third parties. The teams came up with two topics strongly related to energy: (1) a system for CO2 capture for urban mobility, eventually linked with CO2 circularity, and (2) a power electronics box interfacing the grid users, enabling self-operation of electricity grids.

For filtering ideas, we have explored two criteria. The first one is based on the lemma "*disruptive ideas open new markets that did not exist before*". The second criterion is based on the Attractiveness Map [17], which classifies the ideas based on Challenge and Potential estimates. Moonshot ideas score as "super-high challenge" and "super-high potential".

Contrary to the traditional approaches, in Moonshot projects, students must find themselves a high-potential topic, pose the questions, ideate a solution, acquire new knowledge, build a prototype and test it. Full of uncertainty and failed experiences, this process can lead to frustration. Some of the professors' tasks consist of guiding the journey, providing tools and reflections, and keeping their goals ambitious.

After finding the most promising idea, the students do not immediately see the big picture and need some time to mature it. We request students to submit a report describing the Moonshot solution in general terms, do an initial literature review and anticipate the main components of the solutions and activities to do, trying to prioritise them, following Google's lemma: "*hardest things first*".

We encountered two profiles of students. Most of the students have a vague idea of their project and tend to need help in making their vision more concrete and specific.

The challenge for the professors is to guide the ideation process and provide tools and criteria for discarding ideas. Other students have a pre-defined and particular idea of the project, often based on their field of knowledge, without testing its innovation potential. These students can be emotionally attached to their ideas and tend to reject an evaluation of their own idea with objective criteria. The students may perceive the ideation as unnecessary and a handicap for progressing in the topic. A certain degree of detachment is needed to run an objective analysis. Hence, the challenge for professors is to enable the ideation process while playing down (not rejecting) the students' initial ideas.

5 MOONSHOT BUSINESS MODEL

We recall the concept of "*Job-To-Be-Done*" (JTBD) [18], as the ultimate need to be satisfied. We cite its definition [19]: "*JOBS-TO-BE-DONE is best defined as a perspective — a lens through which you can observe markets, customers, needs, competitors, and customer segments differently, and by doing so, make innovation far more predictable and profitable*".

In the example of Henry Ford against animal traction, the JTBD stays the same: the need for mobility "*go from A to B*". Ford's invention converged two technologies: the gasoline motor and the assembly line manufacturing method. Today, Internal Combustion Engine (ICE) cars are being disrupted by Electric Vehicles with self-driving capabilities, which happen to solve the problem of carbon emissions and car mortality with the convergence of breakthrough technologies, such as *light* batteries, sensors, computation power, etc. [20].

When practising with the students, we need to analyse their idea to unveil the JTBD, the value created and for whom it is valuable. Given the scope of energy, we practice with ongoing cases, such as EMROD, for a mid-long distance wireless transfer system [21]. This type of analysis is necessary to draft a business case. For instance, in the project of a CO2 capture device for mobility, the analysis revealed that such a device would create value for a broad range of stakeholders, such as the ICE vehicle owners (especially those more challenging to decarbonise, such as tractors or old vehicles), manufacturers, and municipalities, amongst others.

We practised the Value Creation Ecosystem [22], a useful tool for (1) identifying the relevant stakeholders and the value exchanges between them and (2) representing visually the exchanges, which helps students see the big picture. This tool is best for practising interactively with students, drawing the ecosystem together by asking them questions and letting them come up with the answers.

We also practised the popular Business Model Canvas [18], a beneficial tool to analyse existing businesses and design new ones by "*pivoting the business model*" [23]. In the previous edition of Moonshot Thinking, we observed that they were reluctant to explore changes once the students drafted the first Business Model. This time, we requested students to explore different models inspired by the 55 business model patterns by the Business Model Navigator [24, 25]. This change met our expectations: the students were later more eager to explore alternatives and imagine different ways of monetising their projects. Moreover, having a market and business idea can help students prioritising their efforts in the prototyping phase.

6 IMPLEMENTATION OF RAPID PROTOTYPING

Moonshot Thinking follows an agile approach, emphasising iteration and rapid prototyping to develop effective solutions. However, this process can take up to 10 years in a project setting. Due to time constraints in the subject, the process is condensed to six months by introducing rapid prototyping. This process, which happens within a Fab Lab environment, involves creating a proof of concept and conducting experiments to test the solution.

After receiving foundational knowledge in prototyping technologies such as CAD design, Arduino, and machine learning, the students enter the Fab Lab Barcelona. Their initial experience prototyping involves the "The Almost Useless Machines" module (TAUMs), a three-day intensive introduction to fabrication, physical computing, and the Fab Lab environment. TAUMs teach effective time and resource management during prototyping sprints. Students also gain proficiency in utilising different machines, understanding material impacts on prototypes, and conducting necessary tests before finalising their designs. The TAUMs module encourages creativity, imagination, and problem-solving, resulting in positive student feedback and freedom in the learning process [26].

Once students become familiar with prototyping technologies and the Fab Lab environment, they embark on the Moonshot prototype process. Typically, Moonshot problems require years of dedication and investment, but students only have two 25-hour sprints, making it nearly impossible to prototype their solutions fully. Consequently, students are tasked with creating a proof-of-concept or a representative model of their solution.

The Immersive Learning Experience program, facilitated by the Fab Lab "Accelerator & Prototyping Program," guides students through the prototyping process, equipping them with skills and tools for the future of digital fabrication and distributed manufacturing. This program involves mentoring sessions with Fab Lab experts, focusing on selecting appropriate technology, design, and data to address the problem, considering existing knowledge and available resources. The prototyping experience encompasses guided and autonomous sprints, during which students document the fabrication process, and record encountered challenges, decision-making, and potential improvements for subsequent iterations. In the 2022-23 course, two projects were proposed, including "The Box," a prototype aiming to reduce grid

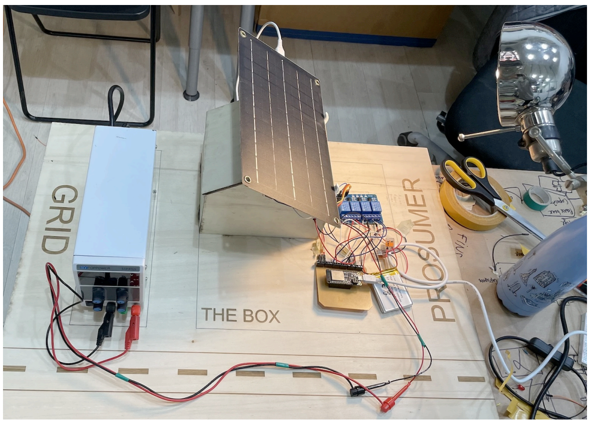

Figure 5. Moonshot Project prototype of the project called “The Box”.

operation costs and enhance performance through a smart grid connection. The prototype, shown in Figure 5, features a low-voltage direct connection microgrid that manages a li-ion battery's charging and discharging behaviour to balance out generation losses from a variable photovoltaic panel. The students acknowledge the prototype's limitations but recognise its potential for future enhancements.

In their final report and presentation, students provided a comprehensive overview of the prototyping process, highlighting encountered challenges, conducted tests, and gained insights. They also outlined the following steps and changes they would implement if the project lasted longer. Rapid prototyping is pivotal in Moonshot Thinking, enabling students to iterate quickly and learn from failures. Collaborating with a Fab Lab adds dynamism and fosters a maker culture perspective.

7 SUMMARY AND ACKNOWLEDGMENTS

This paper presents the results of the pilot implementation of the Moonshot Thinking course for the MSc Innonergy Energy for Smart Cities engineering programme at BarcelonaTech-UPC in Barcelona. This course is challenge-based and adjusted to the Moonshot Thinking approach. Therefore, the methodology of the course implementation of Moonshot Thinking is also presented. The methodology presented above requires a combination of multiple skills and disciplines, coupled with autonomous decision-making by students during the project. This requires a high degree of flexibility on the part of both students and teachers to keep the project's overall goal in mind. On the part of the students, the ability to combine various competencies in an interdisciplinary way is especially challenging. In addition, students are required to come up with unconventional ideas, which is in some ways contrary to what students are required to do in most subjects at university. From the teacher's perspective, the variety of activities requires efficient scheduling of the individual sessions and management of the multiple decision-making processes. A high level of mentoring and interdisciplinary competencies are requested from the lecturers.

The general assessment of the course is positive, and the opportunities for implementing this approach are high, also beyond the engineering sector. Students' motivation for the course is generally high, based on the overall experience of almost three years of implementation. However, a more diverse student profile may result in a more diversified outcome; however, it may also add complexity. Future work will focus on seamlessly systematising the entire methodology and opening it up to a broader range of students as a regular subject at the UPC for energy engineers.

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