“DT MEETS STEM”

A USEFUL MANUAL TO CONNECT STUDENTS WITH REAL-WORLD CHALLENGES

INDEX

INTRODUCTION

Abstract
The **DT MEETS STEM MANUAL** has been developed for professors by professors, aiming to unlock the potential of Design Thinking (DT) applied in Science, Technology, Engineering, and Mathematics (STEM) courses. The manual has been co-created with STEM professors and experts who use Design Thinking daily in their courses, to provide relevant and applicable practical steps for DT implementation - it includes methodologies and techniques, as well as advice based on professors' expertise. To understand the core principles and benefits of Design Thinking, the following chapter will explain the Design Thinking process and motivate you to implement it in your university STEM courses.

Keywords: STEM courses, Design Thinking, Skills

I.I THE PURPOSE OF THE MANUAL

I.I.I BENEFITS OF DESIGN THINKING IN STEM COURSES

The job market demands a broader skill set beyond technical expertise and scientific knowledge, since automation, AI, and other technologies transform it.

As professors, we would like to create opportunities for students to acquire skills and develop mindsets to achieve impactful careers - developing cognitive, social, and adaptive skills that complement technological capabilities is becoming essential nowadays and the manual highlights it by fostering critical thinking, creativity, innovation, collaboration, communication and problem-solving skills. According to research by McKinsey (Dondi, Klier, Panier, Schubert, 2021), interpersonal skills like people management, emotional intelligence, and negotiation will also be crucial as people work alongside intelligent machines. Thus, Design Thinking will benefits STEM courses by:

1. Cultivating critical thinking, creativity, and innovation;
2. Promoting interdisciplinary collaboration and communication;
3. Empowering student agency and problem-solving skills;
4. Building resilience and adaptability in addressing complex challenges;

5. Connecting STEM education to real-world applications with a user-centred approach.

I.I.II A WINNING COMBINATION FOR STUDENTS - DESIGN THINKING x STEM

While Design Thinking is widely used in university courses for product and service innovation, its application in STEM courses offers exciting possibilities. Below there are some successful examples of Design Thinking integration within STEM curricula:

- **Monash University's Tech School** in Melbourne exemplifies how Design Thinking can be a core component of STEM education. They utilise this framework to engage students in interdisciplinary problem-solving and bridge the gap between theoretical learning and industry needs in STEM fields[1]. Students from science, technology, engineering, and mathematics actively participate in the entire DT process, from ideation and prototyping to testing and solution creation.
- The **Polytechnic University of Catalunya (UPC)** showcases DT in action through their Fusion Point courses, a collaboration between ESADE Business School, UPC and European Design Institute (IED) which integrate Design Thinking into multidisciplinary STEM fields such as Computer Science, ICT and Data Science.

These successful implementations demonstrate the effectiveness of Design Thinking in enhancing STEM education.

I.I.III A WINNING COMBINATION FOR PROFESSORS - DESIGN THINKING x STEM

Beyond empowering students, DT offers professors a powerful methodology for crafting innovative learning experiences. This paragraph explores how DT can benefit you in your teaching practice:

- **Create engaging and dynamic courses**: the DT process allows you to design, deliver and evaluate your courses in a continuous cycle, an interactive approach that empowers you to experiment, gather feedback and improve your course, as well as better meet students' needs.
- **Embrace an experimentation mindset**: the dynamic nature of today's student needs requires adaptable teaching methods. DT fosters an experimentation mindset enabling you to test new approaches, refine your teaching strategies and create courses that follow your students' evolving needs and knowledge levels.
- **Develop a User-centred approach**: just like students apply DT to address user needs, you can leverage the same principles to design user-centred courses, focusing on student learning engagement and outcomes.

I.II DESIGN THINKING: a user-centred approach to problem-solving

WHAT IS DESIGN THINKING?

Design Thinking is a creative, human-centred, iterative approach to problem-solving recognised by academic and industry settings as a practical and agile process which engages people in generating innovative solutions to complex challenges. Originally used in design professions, it's now applied to solve complex organisational, social and business challenges.

Tim Brown, CEO and President of IDEO, defines Design Thinking as a method for creating innovative solutions based on users' needs. He emphasises that it's not just about aesthetic products or services, but about creating ideas that truly address consumer's needs and desires. This approach involves:

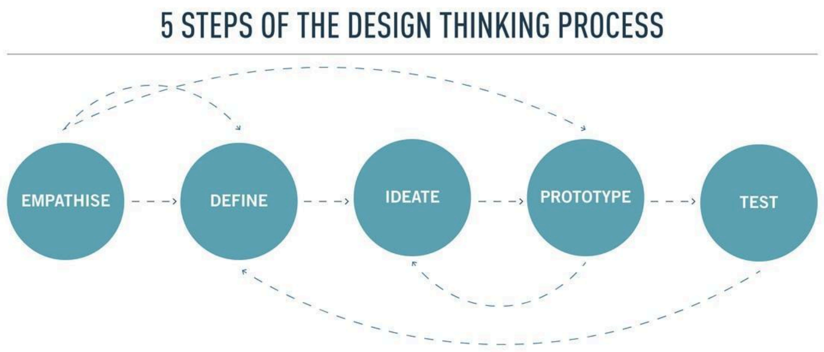
- **Empathy**: understanding users' perspective and needs;
- **Problem definition**: clearly defining the problem to be solved;
- **Ideation**: brainstorming and generating potential solutions;
- **Prototyping**: creating rough models to test and sharpen ideas;
- **Testing**: collecting user feedback on prototypes to iterate and improve solutions;
- **Implementation strategies**: developing plans to play out final solutions.

This holistic, interdisciplinary, and collaborative process uses methodologies from social anthropology, such as ethnography and in-depth interviews, to gain a deep understanding of people and their needs. It is characterised by its experimental, iterative, and user-centred nature, aiming to create solutions that are both technically feasible and viable from a business perspective (Brown, 2008).

THE Design Thinking PROCESS - a step-by-step guide

Design Thinking is an iterative process based on agile methodologies. Let's explore the five key stages that guide you through creative problem-solving:

1. **Empathise**: this stage is all about gaining a deep understanding of the problem by actively empathising with end-users, stakeholders and the community through research methods like user interviews and observations;
2. **Define**: grounded in research and observations, this stage involves clearly defining the core problem statement and identifying key insights and challenges;
3. **Ideate**: get creative! This is where you brainstorm and collaborate to generate a wide range of potential solutions. Think outside the box and explore unconventional ideas;
4. **Prototype**: don't get bogged down in details yet, build low-fidelity prototypes or mock-ups to quickly test and refine ideas. This allows for rapid iteration and exploration of different solutions;
5. **Test**: gather valuable users and stakeholders feedback by testing your prototypes. Analyse the insights collected and use them to iterate and refine your solutions.



Source: What Is the Design Thinking Process? The 5 Steps Complete Guide, https://careerfoundry.com/en/blog/ux-design/design-thinking-process/

This cyclical process guarantees continuous improvements thanks to user responses on prototypes and leads to innovative final solutions that respond to the needs encountered.

EMBRACE THE MINDSET

Design Thinking thrives on an open and experimental mindset. As participants cycle through the process, they cultivate this approach by actively testing ideas, gathering feedback and iterating on their solutions.

INNOVATIVE CHALLENGES - Real-World learning

The best way to integrate DT into your course is through an innovation challenge linked to a relevant STEM question. This method sparks students to gain a deeper understanding of real-world issues by exploring them from different perspectives and it's an opportunity to connect innovation challenges to the UN Sustainable Development Goals, in order to empower students to create solutions with a positive and environmental impact and lead them to solve complex problems by considering both business viability and sustainability.

PROJECT-BASED TEAMWORK - Learning through collaboration

Design thinking is teamwork! In your courses, students will work in teams to tackle these challenges. The more diverse the teams, the better, as it fosters a rich exchange of ideas and perspectives. Typically, teams consist of 5 to 8 members to optimise the group dynamics. Collaborative learning is a fundamental aspect of this process, equipping students with valuable interpersonal, teamwork and communication skills.

How Design Thinking techniques can be implemented into STEM courses so as to introduce students to a new mindset? The next chapter will supply DT phases and tools to help professors and teaching assistants throughout the course development.

I.III APPLYING DESIGN THINKING IN STEM COURSES

Universities can create societal benefits by using Design Thinking to engage civil society (for example, through challenges with impact on society), drive innovation and promote sustainability initiatives (for example by incorporating the SDGs into courses).

Design Thinking has proven to be a powerful tool for creating engaging and impactful learning experiences across various disciplines; it also provides professors with an innovation framework that focuses on adding meaningful values to technical solutions to greater impact on society. It's a relevant and necessary approach in STEM courses to provide students with the opportunity to:

- Experiment with innovation techniques - by applying DT principles, students develop hands-on experience with innovation methodologies highly valued in the job market;
- Acquire essential skills and competences - the DT process favours the development of critical thinking, problem-solving, and creativity, as well as soft competences and an innovative mindset, all crucial aspects for success in STEM fields and beyond.

I.III.I Design Thinking IN STEM COURSES

Design Thinking is a valuable dynamic framework that perfectly integrates key aspects of STEM education:

- **Problem-based learning** - Students face real-world STEM challenges, developing critical thinking and problem-solving skills in a practical context;
- **Interdisciplinary collaboration** - the process encourages cross collaboration between STEM disciplines, mirroring the collaborative nature of real-world work environment;
- **Prototyping and iterative testing** - Students run into real-world experiences first-hand by prototyping and iterative testing, allowing them to refine and improve their solutions;
- **Connecting STEM to Sustainability** - By linking STEM topics with the UN Sustainable Development Goals (SDGs), students learn how to create solutions with a positive global impact;

Overall, Design Thinking is viewed as a transformative approach that can empower students to become creative problem-solvers, critical thinkers, and agents of change in STEM fields and beyond[2] and conduct them to prioritise innovation and user-centred thinking, cultivating a mindset that allows them to apply their knowledge and skills to tackle complex challenges and drive positive change.

I.III.II STEM COURSES - A COMPARISON BETWEEN SCIENCE-BASED AND TECHNICAL-BASED COURSES

STEM degrees are increasingly popular due to the high demand for graduates in the job market. To effectively navigate this guide, let's first clarify the meaning of "STEM" and explore the differences between what we define as science-based and technical-based courses within this field.

STEM, coined in the U.S. in 2001 during a National Science Foundation conference, is an acronym that stands for Science, Technology, Engineering, and Mathematics. While the term STEM is widely used in academia, it's important to note that specific disciplines may vary by country. In Italy, for instance, STEM degrees typically combine scientific and technological studies with a strong emphasis on engineering principles. For the purposes of the DT Meets Stem Manual we decided to differentiate between science-based and technical-based STEM courses - the fundamental distinction lies in the desired learning outcomes of each course.

Science-based STEM Courses

These courses serve as the foundation for understanding the natural and physical world - as a professor teaching science-focused STEM subjects, you play a crucial role in cultivating the next generation of scientists and researchers.

By emphasising the scientific method, quantitative reasoning and experimental techniques you prepare students with essential skills and core competencies for a wide range of careers in research, healthcare, environmental sciences, and other scientific fields and you lay the groundwork for advanced studies in STEM fields. The key characteristics of these science-based STEM courses are:

- **Focus on natural and physical world** - through theoretical knowledge, empirical observation, in-depth exploration and experimentation, students understand the fundamental laws governing the natural world and strengthen their scientific skills;
- **Application of scientific method** - Students apply this method to investigate phenomena, test hypotheses and draw conclusions;
- **Request of proficiency** - Students learn how to be proficient in mathematics, data analysis and problem-solving to model and explain scientific concepts;
- **Laboratory activities** - This type of courses often have laboratory components where students gain hands-on experience with scientific equipment and procedures.

Overall, these science-focused STEM courses equip students with the **knowledge, skills, and critical thinking abilities needed to pursue careers as scientists, researchers, and technical professionals** in a variety of industries and sectors. They form the foundation for many advanced STEM-related studies and applications.

Technical-based STEM Courses

Technical-focused STEM subjects equip students with fundamental skills to thrive in the world of work. By emphasising programming, software development, digital systems and emerging technologies, these programs prepare graduates for a wide range of careers in the tech industry, research and development, and other technology-driven fields. The key characteristics of these technical-based STEM courses are:

- **Focus on design, development and application of new technologies** to solve problems and create innovation. Students learn to translate scientific knowledge into real-world solutions by applying design thinking, problem-solving techniques and technological tools. The purpose of these courses lays in the development of tangible artefacts;

- **Involvement of digital skills** - Students study programming languages, algorithms, data structures and software engineering principles to immerse themselves in the digital age and apply their knowledge in the job market;
- **Request of proficiency** - Students learn how to be proficient in mathematics, logic and problem-solving to model and analyse complex systems;
- **Laboratory activities** - Students often participate at hands-on laboratory activities to gain practical experience with hardware and software tools.

Overall, these technical-based courses provide the essential building blocks needed to pursue careers as software engineers, data analysts, cybersecurity specialists, robotics engineers, and other technology professionals in a variety of industries. They form the foundation for many advanced STEM-related studies and applications.

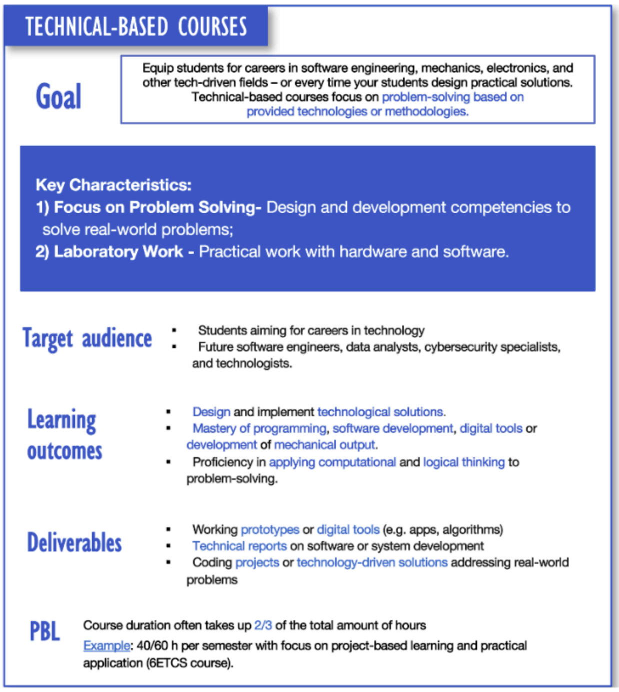
Science-based STEM Courses	Technical-based STEM Courses
➢ Biology ➢ Chemistry ➢ Physics ➢ Astronomy ➢ Biochemistry ➢ Geology ➢ Ecology ➢ Meteorology ➢ Oceanography ➢ Zoology	➢ Computer Science ➢ Information Technology (IT) ➢ Mechanical system control ➢ Advanced Mechanical Systems Design ➢ Materials Technologies ➢ Cybersecurity ➢ Data Science ➢ Robotics and Artificial Intelligence ➢ Virtual Reality ➢ Biotechnology ➢ Nanotechnology

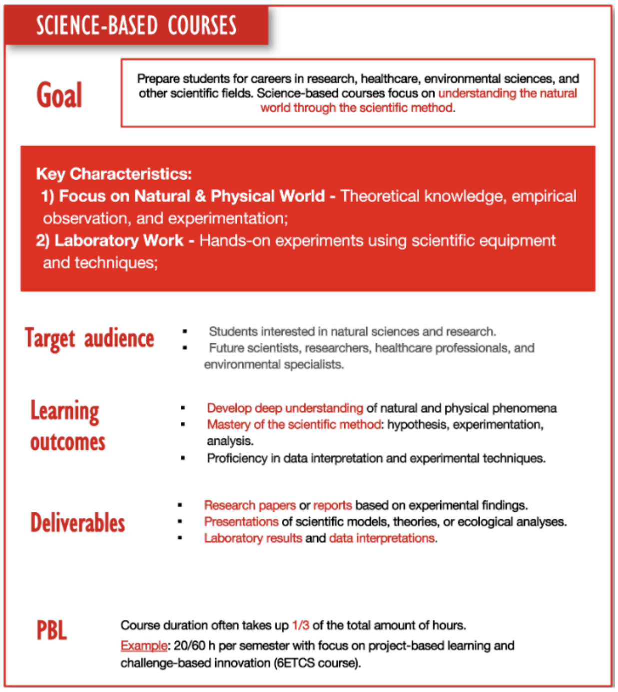
Why should we distinguish between science-based and technical-based STEM Courses?

This breakdown helps identify the specific focus of each course and how PBL can be adapted to its unique learning objectives. For instance, a science-based project in Biology might involve researching the effects of climate change on a particular ecosystem, such as studying the impact of rising ocean temperatures on coral reefs. Students can analyse data, conduct experiments and develop models to understand the ecological consequences.
On the other hand, a tech-based project in Computer Science could involve developing a mobile application to address a specific social need related to climate change. This could be an app that helps users track their carbon footprint, provides real-time air quality data, or gamifies sustainable practices to encourage eco-friendly behaviour. By applying their coding skills and understanding of user experience design, students can create a tangible tool that empowers individuals to participate in climate action.

The **DT MEETS STEM MANUAL** will provide professors and teaching assistants with processes, methodologies and practical guidelines for the design, development and evaluation of Design Thinking in STEM courses.

The table below clarifies the differences between the two course types, helping you easily identify which one applies to you.





I.IV A GUIDE TO THE MANUAL

This manual is designed for professors to help them integrate Design Thinking into university STEM courses. To ensure smooth navigation, we've structured a useful guide you can use to move between chapters and find the information you need.

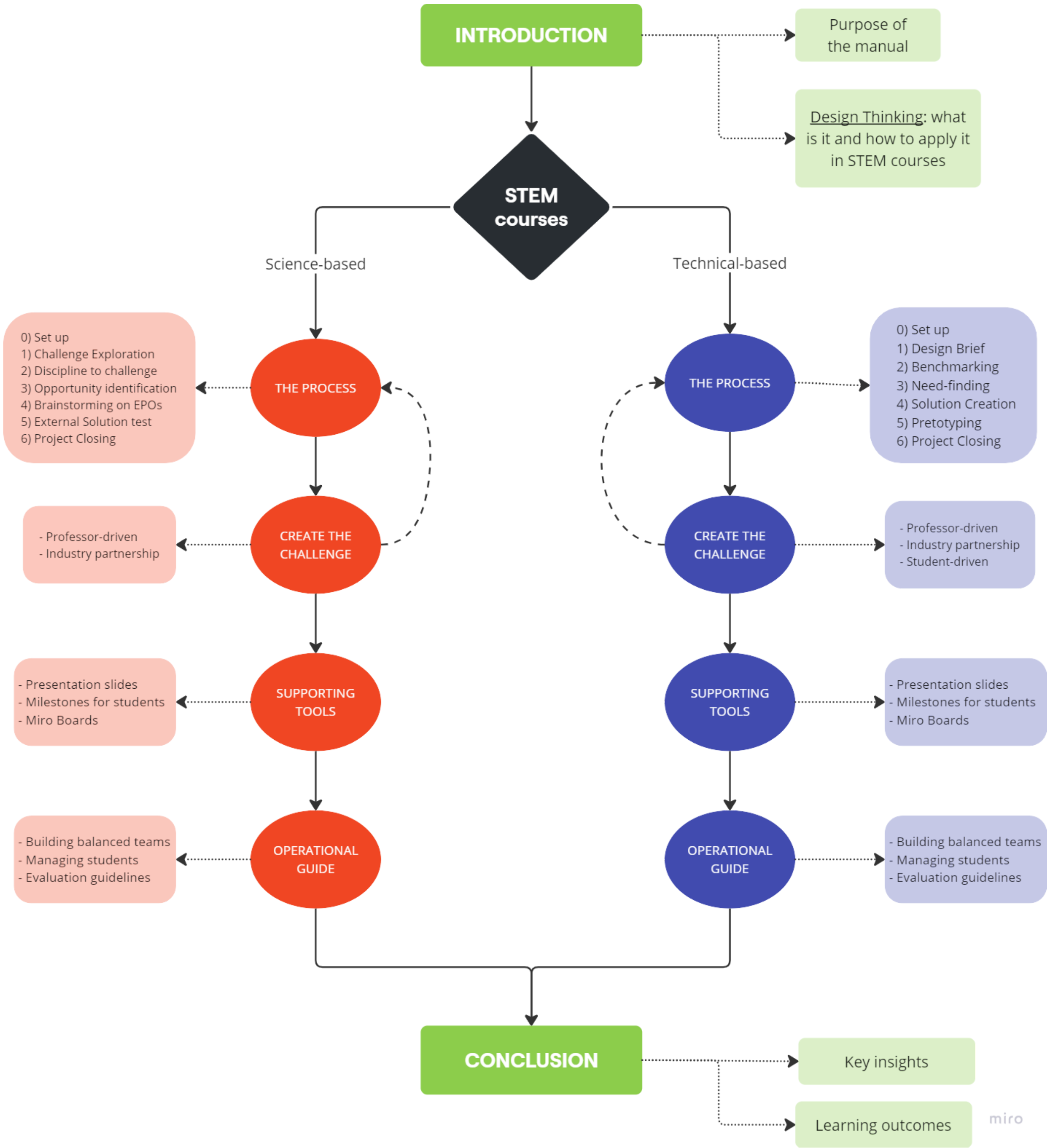
INTRODUCTION	This chapter introduces STEM courses by differentiating between science-based and technical-based courses. You will dive into the structure of the Design Thinking (DT) process, tailored for both types of courses, and end up with this useful guide.
Chapter 1 **PROJECT DEVELOPMENT: Technical-based process**	This chapter focuses on a technical-based process to help you implement PBL in your syllabus. From the structure and the creation of a meaningful INNOVATION CHALLENGE, to the supporting tools section and the operational aspects of integrating DT in your course, the chapter offers practical guidelines to develop students' DT mindset that align with course objectives and their interests. The last part provides insights into assessing student performance in DT projects, considering both individual and teamwork components.
Chapter 2 **PROJECT DEVELOPMENT: Science-based process**	This chapter focuses on a science-based process to help you implement PBL in your syllabus. From the structure and the creation of a meaningful INNOVATION CHALLENGE, to the supporting tools section and the operational aspects of integrating DT in your course, the chapter offers practical guidelines to develop students' DT mindset that align with course objectives and their interests. The last

	part provides insights into assessing student performance in DT projects, considering both individual and teamwork components.
Chapter 3 **Summary and Additional resources**	This chapter summarises the benefits of integrating Design Thinking (DT) in STEM education and highlights key learning outcomes such as enhanced problem-solving, creativity, collaboration, and professional readiness, distinguishing between technical-based courses and science-based courses. The chapter also points to future developments, including long-term impact measurement and the role of technology in facilitating DT.

By following this structure you will gain a clear understanding of Design Thinking, its application in STEM courses and the steps required for successful implementation.

Here you can find an overview table of the entire manual to provide readers a helpful tool to go through the document. The final chapter should be consulted as a summary and conclusion, reinforcing key points and offering additional resources.

If you identify your course into the science-based courses, jump directly to CHAPTER 2 "*PROJECT DEVELOPMENT: Science-based Process*"!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THE PROCESS
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CHAPTER 1

PROJECT DEVELOPMENT: TECHNICAL-BASED PROCESS

Abstract
Project-based learning (PBL) is a powerful approach that helps students bridge the gap between theory and practice. By engaging in real-world or simulated projects, students actively apply their knowledge to solve problems and develop valuable skills for their future careers. This guide focuses specifically on implementing PBL in STEM courses (Science, Technology, Engineering, and Mathematics). To provide a clearer framework, we categorise STEM courses into two main areas: science-based and technical-based. This section will clarify the role of PBL in technical-based courses, outline the recommended PBL process for integrating projects into your syllabus, provide and refine guidelines for creating the challenge and explore the supporting tools available to facilitate its successful implementation. Additionally, there's an operational guide supplied to assist you managing your student teams and evaluating them fairly and equitably.

Keywords: Project-based learning, STEM courses, technical-based courses, process, challenge, supporting tools, student groups, evaluation

1.1 STRUCTURE OF THE PROCESS

Technical-based courses have their focus on the application of theory to real-world cases to guide students toward nowadays digital-age job market. According to this purpose, Project-based Learning (PBL) helps professors cultivate required skills and competences of students in order to increase the number of potential new aware and trained workers.

Introducing a project into a course syllabus is not as simple as it can be perceived, the process must be organised to increasingly empower students along their exploration and development of solutions and at the same time letting them proceed by themselves and feel supported throughout the entire personal and team growth. As a professor, you will follow the project development step by step, guiding students to their final solution - you will no longer be their professor but will rather become their companion.

1.1.1 TRIDIMENSIONAL PROJECT-BASED LEARNING: A MULTI-PERSPECTIVE PROCESS

Every day technical-based subjects are facing a crucial aspect for real-world applications: FEASIBILITY. The feasibility feature of a process output is absolutely important but it's not the only guideline to follow during a project development. Design Thinking techniques underline the useful intersection of this dimension with two others, viability and desirability, that are contributing to create value to all the stakeholders involved in the project. By viability we refer to a solution that is economically feasible and implementable, while we speak of desirability when there's evidence of a real need to which the solution responds and when it stands out from the competition. Dealing with these three dimensions and acting between their intersections is fundamental to understanding how to build up a strategic path and raise DT awareness in your students.

The suggested steps below will conduct you to integrate and potentiate PBL with particular attention to desirability first, viability and feasibility later.

0. **SET UP**: This is the initial phase, students are assigned to a specific challenge and they start to keep confidence with it. The team is grouping together for the first time and it's going to define team rules and roles, set supporting tools such as miro boards and participate to socialising activities to increase group membership;

1. **DESIGN BRIEF (1 week)**: It's the comprehension phase of the process, the team must clarify the final object according to stakeholder expectations and should deliver a signed document declaring the output features targeted. The team focuses on specifying the challenge not in terms of implementing a solution, but by solving the problem!

   DELIVERABLE 1 ⇒ Design Brief document

2. **BENCHMARKING (1 week):** During this phase the team members engage in researching information regarding the project topic in order to gather knowledge on the challenge. Moreover, they analyse the possible stakeholders and assign them a strategic position on the "Stakeholder map" tool.
3. **NEED-FINDING (1 week)**: Need-finding is the moment when students should gather opinions and information from stakeholders identified in the previous phase. The team carries out empathic interviews and conversations to extrapolate end users' needs in order to create the so-called "personas".

4. **SOLUTION CREATION (1 week)**: This is the convergence phase during which the team sketches the first technical and economic characteristics. The team members develop different solutions using Brainstorming and other creative techniques to bring out problem-solving ideas, ending with the identification of three main solutions.

5. **PRETOTYPING (1 week)**: Pretotyping is the final test to understand the possible product desirability and differs from Prototyping because it doesn't measure product functionality, i.e. its feasibility. By exploring the solutions resulting from the previous phase, students are able to decide on the solution that seems most implementable and create the final proposal with all the required technical features to be proposed to the client.

   DELIVERABLE 2 ⇒ Technical Proposal (Data Sheet) : It is a board comparable to a product identity card that reports the product characteristics, price included.

From this point the iteration phase starts: students are supposed to develop two different deliverables at the same time, one concerning the economic assessment and the other one about the technological solution - these documents must be compiled simultaneously to improve technological features while respecting the budget set by the client, pursuing viability and feasibility dimensions.

DELIVERABLE 3 ⇒ Economic evaluation

DELIVERABLE 4 ⇒ Technological solution

6. **PROJECT CLOSING**: Once the project output is completed, the team must deliver his project report and prepare the final presentation. Furthermore, students are required to write a personal reflection about their experience throughout the entire process in which they report their learning journey as well as their considerations regarding what aspect they would like to keep in their future life and how the project changed their mindset. To learn more about the personal reflection you can consult the " **1.4.4 EVALUATION** " paragraph.

DELIVERABLE 5 ⇒ Final presentation

DELIVERABLE 6 ⇒ Personal Reflection document (Consult the **ANNEX**)

During the entire period the team has to compile a report - maximum 5 pages, one per week - that describes the entire development process of the solution and tracks the turning points which led to the final solution.

1.2 CREATE THE CHALLENGE

A well-defined challenge is the cornerstone of any successful Design Thinking project - it provides the focus and directions for the entire process. As a professor, implementing PBL techniques will make you face the difficulty of creating an appropriate challenge that effectively motivates your students.

A compelling Design Thinking (DT) challenge should be:

- **Human-centred:** Rooted in real-world problems or needs experienced by people to ensure that students focus on creating solutions with legitimate impact;
- **Specific:** Clearly defined and without ambiguity. A well-articulated challenge provides a clear starting point for students' exploration;
- **Inspiring:** Capable of igniting creativity and innovation. The challenge should be sufficiently difficult to encourage out-of-the-box thinking while remaining achievable and it must be perceived as an opportunity to apply theoretical knowledge to practical problem-solving.
- **Feasible:** Aligned with the project's constraints, including time, resources, and student capabilities.

To generate suitable challenges according to your course field or your teaching methodologies, below there are three primary approaches to explore. Regardless of the chosen approach, the ultimate goal is to generate multiple potential solutions from a single challenge and to individualise a final solution that is desirable by the user, technologically feasible and economically viable simultaneously. Professors can create engaging and impactful Design Thinking challenges that enhance student learning and iterative process implementation and prepare them for real-world problem-solving, encouraging critical thinking and a deeper understanding of the DT methodology.

PROFESSOR-DRIVEN CHALLENGES

The professor creates and presents a challenge to the entire class. This method offers a structured approach, ensuring consistency among student projects and fairness of judgement in the final evaluation since the challenge is the same for every group of students. However, it's crucial to present a broad challenge rather than a specific problem, students should be encouraged to identify the core issue from the challenge and develop their projects accordingly.

Here are the steps we suggest you to follow in order to create a challenge:

1. **Identify a Problem or Need:**
    a. Start with a broad area of interest**:** *What problems do you or your students see in your community, industry, or personal life? What are you passionate about?*
    b. Narrow down the focus**:** *Choose a specific problem or need within that area.*
    c. Consider the user perspective**:** *Who is affected by this problem? What are their challenges and frustrations?*
2. **Frame the Challenge:**
    a. Use clear and concise language**:** *Avoid technical language or overly complex phrasing.*
    b. Focus on the desired outcome**:** *What do you want to achieve?*
    c. Consider the constraints**:** *What are the limitations or boundaries of the project?*
3. **Test the Challenge:**
    a. Share it with others**:** *Get feedback on whether the challenge is clear, inspiring, and feasible.*
    b. Refine as needed**:** *Make adjustments based on the feedback received.*

Two examples to be inspired by are provided in order to understand how to set up the challenge.

Broad area: Computer Science
Specific problem: Employees struggle with debugging code effectively, leading to frustration and lost time.
Challenge: Develop a tool or method to reduce the burden caused by bad code.

Broad area: Engineering
Specific problem: Elderly patients with mobility issues struggle to move in the hospital.
Challenge: Create a solution that enhances the independence and safety of elderly patients with mobility issues while they are hospitalised.

Make sure the challenge is achievable within the given timeframe and resources and remember it may evolve as students learn more about the problem - you can also push them to explore the challenge and edit it according to the results obtained from the need-finding phase (1.1.1 THE TRIPLE BOTTOM LINE: a multi-perspective process), since the process has a fundamentally iterative approach.

Directly engaging with potential users can help you find invaluable insights into their needs, frustrations and desires, as well as observing people in their natural environment can reveal hidden challenges and opportunities. To create the challenge, you can also gather industry data that can help you identify trends and consumer behaviour, or you can consult academic studies, news and media to remain updated with current events and emerging issues.

Furthermore, analysing successful design projects can inspire new challenges ideas:

- **Nielsen Norman Group:** This website offers expert insights into user experience and usability.
- **IDEO:** Known for its innovative design approach, IDEO shares case studies and methodologies.
- **Stanford d.school:** Offers resources and courses on design thinking.
- **HCD Institute:** Provides information and training on human-centred design.

By carefully considering your target audience, their specific needs and goals of your project, you can clearly understand which sources are more relevant and provide a unique project-based learning to your students.

INDUSTRY PARTNERSHIP

Collaborating with companies and public organisations can provide real-world challenges for students. This approach offers opportunities for authentic learning and potential career connections. The professor can establish a partnership with some companies - that will present the challenge encountered in their organisation to students - and he must ensure the challenges are suitable for the course objectives.

STUDENT-DRIVEN CHALLENGES

Empowering students to identify challenges and partner with companies fosters independence and entrepreneurial skills. Students are supposed to look for a company that wants to collaborate with them. The professor’s role is primarily supportive and essential for providing guidance and resources, but also of control, as he has to evaluate the appropriateness and approve the challenges proposed by the students.

1.3 SUPPORTING TOOLS FOR EFFECTIVE IMPLEMENTATION

This section introduces all the resources included at the end of this manual (appendix) to support your successful implementation of Design Thinking (DT) within your STEM courses using project-based learning. These tools are designed to deal with various teaching styles and student needs, allowing you to tailor your approach based on your teaching modality, course content and students. Experiment and explore to find and select the resources that seem most effectively and suitable for your course and students.

1.3.1 PRESENTATION SLIDES

A comprehensive presentation slide deck allows you to introduce DT to your students in a clear and engaging manner. Every deck of slides refers to a specific Milestone and is then relevant to the lesson it is referring to. As a professor, you can use these slides as a tool that helps you to introduce the PBL and the several techniques students are going to learn during your course.

1.3.2 MILESTONES FOR STUDENTS

Milestones serve as structured, step-by-step guidelines outlining the tasks to be completed by a specific deadline: these documents are aligned with the presentation slides discussed in the previous paragraph and will support you throughout the Project-based Learning activity. For each stage of the project, a document is provided detailing the objectives students are expected to achieve within the given timeframe. These documents include a well-defined path and comprehensive descriptions of suggested tools and resources that are essential for the development and success of the project. Students may reference these milestone documents at any time to ensure they have clearly understood instructions and they’re on the right way toward their final deliverables.

1.3.3 MIRO BOARDS

An online collaborative platform called Miro is included as a resource. Miro allows students to work together virtually, brainstorming ideas, visually organising project information, and creating mind maps in real-time. This fosters a collaborative learning environment and enhances communication within student teams. The board is thought to be used and edited by the team as it’s dealing with the challenge, so that students will easily follow the structured process: its templates mirror the Milestones documents and Presentation slides provided and help students understand what and when to do the required tasks.

Here is the access to the Miro Board:
https://miro.com/app/board/uXjVLPnGSk0=/?share_link_id=626323210028

1.4 OPERATIONAL GUIDE - cultivating student success in project-based learning

This section equips you with the tools and strategies to create a supportive and productive learning environment for your course. Here we are going to dive into group formation, student management throughout the project lifecycle and effective evaluation methods. Understanding the student experience is the cornerstone of exploring potential challenges and guiding students towards successful resolution.

In this guide, Project-based learning (PBL) is implemented as a mandatory component of a course; however, there are situations where non-mandatory projects can be a valuable alternative to approach the transition to PBL method. We will explore the advantages and disadvantages of each approach to help you decide which aligns best with your course objectives.

1.4.1 BUILDING BALANCED TEAMS

"When people interact in a positive way, energy is not dissipated and differences are valued as opportunities to learn." (Hills, 2001)

The composition of your student groups significantly impacts project success. Teams work well in optimistic environments and when personalities clash, energy is spent in unproductive behaviour and no value is placed on diversity. This is the main reason why professors should focus on understanding the interplay between students in order to create high-performance teams.

Here are some key points to take in account while creating balanced teams:

- **Skills and learning styles**: pursuing diversity in skills, backgrounds and learning styles will foster a richer learning experience through collaboration and knowledge exchange. Consider creating teams in which strong research abilities, analytical skills, creative problem-solving approaches and excellent communication skills coexist.
- **Personalities**: consider a mix of personalities to ensure balance of ideas and approaches. While some students excel at brainstorming sessions and leading discussions, some others may be more profitable in data analysis, organisation and technical expertise.
- **Student preferences**: instructor-assigned groups can be effective but, whenever possible, incorporating student preferences can increase motivation and team dynamics. Therefore, use surveys or short questionnaires to take into account student preferences on a particular argument to work on.

To foster a dynamic learning environment, we strongly recommend conducting a brief survey after introducing a project in class. Analyse students' answers to create balanced teams that represent different learning backgrounds and academic disciplines: this allows students to feel they're giving a valuable contribution to the project team by sharing their unique skill set.

If then your project offers students a choice of topic or approaches, incorporate those options into the survey: by giving students the possibility to express their preferences , you can tap into their intrinsic motivation and keep them engaged throughout the entire project process.

In the **ANNEX** at the end of the manual there's a small example of how the survey could be structured.

1.4.2 MANAGING STUDENTS THROUGHOUT THE PROJECT JOURNEY

Students are the driving force behind successful PBL courses. To ensure their optimal experience, we are introducing some useful concepts:

- **Setting clear expectations**: clear outline project goals, timelines, deliverables and evaluation criteria since the beginning. This provides a roadmap for students and promotes a right direction to follow. Consider creating a project charter document that summarises these instructions and acts as reference for student teams.
- **Open communication**: establish open communication channels to address student doubts and concerns and provide prompt feedback during project development. Encourage students to share questions, roadblocks or emerging challenges with the class by using online discussion forums, dedicated project check-in sessions or classroom hours to facilitate communication.
- **Promoting collaboration**: Promote teamwork and collaboration skills supporting students in discussions, brainstorming sessions and group decision-making to foster a collaborative climate. Utilise online tools such as shared documents, project management platforms, miro boards or video conferencing virtual rooms to enable effective teamwork, especially for geographically dispersed teams.
- **Identifying and addressing challenges**: Be prepared to identify and deal with common challenges such as time management, group conflicts or lack of clarity on specific tasks. Offer a point of reference for conflict resolution strategies and support mechanisms to help students overcome obstacles. Remember to provide resources on time management techniques and communication strategies for solving group conflicts and facilitating peer mediation.

How to deal with large classes, for example over 50 students?

This can present a real challenge for professors, but with strategic planning it's possible to create an engaging and productive learning environment. A recommended approach based on successful practices from experienced professors is allocating weekly sessions for team meetings. Dedicating one lecture per week specifically for team meetings can significantly enhance student engagement and project management. This approach allows you to monitor progress closely and provide timely feedback, while also fostering a sense of community among students. Team meetings can be conducted either offline (in-person) or online, each offering distinct benefits.

OFFLINE FOLLOW-UP

Organise these sessions during a designated lecture time where student teams can meet in the classroom and share their work so far. Here are the advantages :

- **Interactive Consultations**: Teams attend the session and receive personalised consultation from you. This direct interaction allows you to address their questions and concerns in real time;
- **Shared Learning**: While waiting for their turn, students can observe the discussions of other teams. This not only helps them learn from their peers' challenges but also encourages cross-team collaboration and idea exchange;
- **Building Community**: The face-to-face setting fosters a stronger sense of belonging and collaboration among students. The physical presence in the same space can enhance team dynamics and promote a collective learning atmosphere.

ONLINE FOLLOW-UP

For greater flexibility, consider hosting these meetings online. Here's how to maximise the benefits:

- **Convenient Access**: Online meetings provide students with the flexibility to join from various locations, accommodating different schedules and time zones;

- **Focused Sharing**: During these virtual sessions, teams can present their work and receive focused feedback. The online format often encourages students to be more concise and organised in their presentations;
- **Enhanced Participation**: Some students may feel more comfortable participating in an online environment, leading to more active and inclusive discussions.

Whichever method you choose, the key is consistency and clear communication. Regular, structured meetings—whether offline or online—help students stay on track with their projects and provide a platform for continuous learning and collaboration. By fostering these interactions, you can effectively manage large classes and ensure that all students have the opportunity to succeed. And if you have the opportunity to be helped by a teaching assistant you can lead these meetings with him to increase efficiency and follow students in an easier way!

1.4.3 HOW TO MANAGE A NON-MANDATORY PROJECT

While PBL is recommended as mandatory course-development, there are situations where non-mandatory projects might be a valid option. Here are some key points to consider:

- **Motivation and engagement**: non-mandatory projects require a strong focus on project design and clear communication of its value for achieving a certain level of expertise. Emphasise strong connection of projects to real-world applications, career development and potential skills acquisition to motivate participation.
- **Adapting management strategies**: with a non-mandatory project you may need to adapt your course management strategies. Focus on intrinsic motivation and self-directed learning, provide clear project guidelines and resources and allow students more autonomy in their project approach to invite them to join the project. Be prepared for potentially lower participation rates and adjust course schedule accordingly. You may also consider offering extra credit or bonus points to those students participating in the non-mandatory project.

1.4.4 EVALUATION

Evaluating student’s learning in projects requires a multifaceted approach that considers both individual and team contribution. To arrive at a final grade that reflects a student's overall performance, we recommend using a combination of evaluation methods. Each method should be assigned a specific weight to contribute to the final grade, ensuring a balanced assessment: for example, a practical approach might be to assign 50% to “Quality of the Output,” 20% to “Peer-to-Peer Evaluation,” and 30% to “Student Reflection.” Below is a detailed explanation of these evaluation methods.

QUALITY OF THE OUTPUT (group evaluation);

Assess the final project outcome based on predetermined criteria and assign a grade to the entire group. This method works well when all teams face the same challenge; for projects with varying challenges, use clear evaluation methods to allow fair comparisons between groups. Consider incorporating indices that let students understand evaluation criteria and performance level achieved in each aspect of the project output.

PEER TO PEER EVALUATION (personal contribution)

Implement anonymous peer evaluation to assess individual contributions to the project. Students can rate on a scale (e.g. 1-5 or 1-10) based on participation, effort, teamwork skills and contributions to the specific project tasks. This evaluation should be anonymous to induce students rating objectively and truthfully. To assist you in the evaluation process, we've provided an Excel template that can be used to calculate individual grades. These grades, combined with the student's self-reflection and group evaluation scores, will contribute to the final grade

STUDENT REFLECTION (experiential learning)

Experiential learning, as proposed by Kolb in 1984, is one of the most effective methods of learning (Kolb, 1984). It allows for serendipitous discoveries throughout the process and provides learners with first-hand experiences in practical, contextualised settings. However, the theorist emphasises that experiential learning is only effective when learners reflect on their experiences, enabling them to abstract and generalise learning points for application in diverse contexts.

Providing students with a framework for effective reflection is crucial to the learning process. This practice also contributes to the development of "learning to learn" competence, one of the eight key competencies of non-formal education proposed by the European Commission's framework.

Since reflection is an ongoing process that becomes more effective with frequency and depth, we have developed reflective diaries (templates are given as “Tools”) based on the Gibbs (1988) model. These diaries provide a structured framework and guiding questions to help learners reflect on their experiences.

We recommend basing a component of your evaluation on reflection. To support this, we have developed guidelines for students to create a final reflection deliverable for the course. This approach allows you to evaluate how well learners have capitalised on their experiences for personal growth, rather than assessing general performance, which can be challenging to define in experiential learning where each student undergoes a unique experience.

We suggest allocating 30% of the final grade to this reflective deliverable. The assessment should be based on the following criteria:

Variety - Evaluate the range of aspects the learner has included in their reflection. Examples may include:

- content of the challenge;
- application of theoretical concepts in real-world contexts;
- time management throughout the process;
- engagement and collaboration with peers;

Depth - Assess how thoroughly the learner has reflected on each aspect presented:

- Have they provided specific examples to support their reflections?
- Have they abstracted and generalised their conclusions?
- Have they considered how to apply their learnings in future situations?

Relevance - Determine the applicability of the reflected aspects to the student's professional life:

- Has the learner connected their reflections to the course content?
- Have they built upon the theoretical material and frameworks provided during the course?
- Are their insights relevant to their future professional development?

CHAPTER 2

PROJECT DEVELOPMENT: SCIENCE-BASED PROCESS

Abstract

Project-based learning (PBL) is a powerful approach that helps students bridge the gap between theory and practice. By engaging in real-world or simulated projects, students actively apply their knowledge to solve problems and develop valuable skills for their future careers. This guide focuses specifically on implementing PBL in STEM courses (Science, Technology, Engineering, and Mathematics). To provide a clearer framework, we categorise STEM courses into two main areas: science-based and technical-based. This section will clarify the role of PBL in science-based courses, outline the recommended PBL process for integrating projects into your syllabus, provide and refine guidelines for creating the challenge and explore the supporting tools available to facilitate its successful implementation. Additionally, there's an operational guide supplied to assist you managing your student teams and evaluating them fairly and equitably.

Keywords: Project-based learning, STEM courses, science-based courses, process, challenge, supporting tools, student groups, evaluation

2.1 STRUCTURE OF THE PROCESS

Science-based courses (hard science and social science) have their focus on linking theory to real-world cases to help students understand how discipline works in the context of the challenge. According to this purpose, Project-based Learning (PBL) helps professors cultivate required skills and competences of students in order to increase the number of potential new aware and trained workers.

Introducing a project into a course syllabus is not as simple as it can be perceived. The process must be organised to increasingly empower students along their exploration and development of solutions and at the same time letting them proceed by themselves and feel supported throughout the entire path. The project can be developed also during extra-school hours but the process to be followed must be introduced in class.

As a professor, you will guide and assist students to their final solution - you will no longer be their professor but will rather become their companion.

2.1.1 THE PROCESS

Design Thinking is a process to be introduced at the beginning of the PBL dedicated lesson. You can decide how many hours you want to allocate to develop the techniques students will learn, but we suggest you organise a 3 hour lesson to let them focus on the topic and clarify the final purpose of the project.

Once students understand the method, the suggested steps below will conduct you to integrate and potentiate PBL into your syllabus.

0. **SET UP**: This is the initial phase, students are assigned to a specific challenge and they start to keep confidence with it. The team is grouping together and it's going to define team rules and roles, set supporting tools such as miro boards and start socialising to increase group membership;

1. **CHALLENGE EXPLORATION (30 min)**: It's the comprehension phase of the process, the team must clarify the final object according to stakeholder expectations and should create an internal presentation documenting the scientific exploration conducted.

   The team focuses on specifying the challenge not in terms of implementing a solution, but by understanding the problem!

   DELIVERABLE 1 ⇒ Challenge presentation

2. **DISCIPLINE TO CHALLENGE (30 min)**: Understand how discipline interacts with the challenge, benchmarking on how it has been faced by means of specific methodologies or solutions.

3. **OPPORTUNITY IDENTIFICATION (45 min)**: EPOs are tools made for the "Opportunity identification" phase, highlighting Evidences, Problem and Opportunity. In particular, you should collect evidence proving the challenge field is important, then you are supposed to develop an opportunity related to the problem identified in the first phase. In order to facilitate the next convergence step, you must develop at least 2 EPOs containing two possible opportunities each.

4. **BRAINSTORMING ON EPO (45 min)**: Using Brainstorming technique and other creative techniques, the team members bring out problem-solving ideas and end up with the identification of different possible solutions linked to the EPOs developed in the previous step. Once they manage to discover how to implement and test their solutions, students must decide which solution to pursue (convergence phase). This is the last activity to be done in class, students must complete the remaining steps independently outside of university hours.

   DELIVERABLE 2 ⇒ EPOs. Students must share with the class the opportunities identified by using techniques for diversification.

5. **EXTERNAL SOLUTION TEST (up to students)**: Students must test the implemented solution in a real environment experiencing the specific challenge, editing their solution according to the feedback received, if needed. This activity should be carried out outside of classroom hours.

6. **PROJECT CLOSING**: Once the solution is tested, students are required to send to their professor a deliverable, that can be an infographic or a video clip (you can use *flexclip*, create max 2-3 min of videoclip). If the number of students is small (i.e below 50 students) you may want to consider the option of having the project outputs exposed during a dedicated class, the DEMO-DAY, to enhance students' presentation skills and anchor the experience to their learning path.

   DELIVERABLE 3 ⇒ Infographic/Video clip: students show their results after having tested them and gathered users' feedback.

Within that day students are supposed to deliver their personal reflection on the project experience, in which they report their learning journey as well as their considerations regarding what aspect they would like to keep in their future life and how the project changed their mindset. This reflection will be used to evaluate their experiential learning (to learn more about the personal reflection you can consult the " **2.4.3 EVALUATION: STUDENT REFLECTION ON THE EXPERIENTIAL LEARNING**" paragraph).

<u>DELIVERABLE 4</u> ⇒ Personal Reflection document (Consult the **ANNEX**)

2.2 CREATE THE CHALLENGE

A well-defined challenge is the cornerstone of any successful Design Thinking project - it provides the focus and directions for the entire process. As a professor, implementing PBL techniques will make you face the difficulty of creating an appropriate challenge that effectively motivates your students.

A compelling Design Thinking (DT) challenge should be:

- **Human-centred:** Rooted in real-world problems or needs experienced by people to ensure that students focus on creating solutions with legitimate impact;
- **Specific:** Clearly defined and without ambiguity. A well-articulated challenge provides a clear starting point for students' exploration;
- **Inspiring:** Capable of igniting creativity and innovation. The challenge should be sufficiently difficult to encourage out-of-the-box thinking while remaining achievable and it must be perceived as an opportunity to apply theoretical knowledge to practical problem-solving.
- **Feasible:** Aligned with the project's constraints, including time, resources, and student capabilities.

To generate suitable challenges according to your course field or your teaching methodologies, below there are two primary approaches to explore. Professors can create engaging and impactful Design Thinking challenges that enhance student learning and iterative process implementation and prepare them for real-world problem-solving, encouraging critical thinking and a deeper understanding of the DT methodology.

PROFESSOR-DRIVEN CHALLENGES

The professor creates and presents a challenge to the entire class. This method offers a structured approach, ensuring consistency among student projects and fairness of judgement in the final evaluation since the challenge is the same for every group of students. However, it's crucial to present a broad challenge rather than a specific problem, students should be encouraged to identify the core issue from the challenge and develop their projects accordingly.

Here are the steps we suggest you to follow in order to create a challenge:

1. **Identify a Problem or Need:**
    a. Start with a broad area of interest: *What problems do you or your students see in your community, industry, or personal life? What are you passionate about?*
    b. Narrow down the focus: *Choose a specific problem or need within that area.*
    c. Consider the user perspective: *Who is affected by this problem? What are their challenges and frustrations?*
2. **Frame the Challenge:**
    a. Use clear and concise language: *Avoid technical language or overly complex phrasing.*

b. Focus on the desired outcome**:** *What do you want to achieve?*
c. Consider the constraints**:** *What are the limitations or boundaries of the project?*

3. **Test the Challenge:**
    a. Share it with others**:** *Get feedback on whether the challenge is clear, inspiring, and feasible.*
    b. Refine as needed**:** *Make adjustments based on the feedback received.*

Here are two examples to be inspired by in order to understand how to set up the challenge.

Broad area: Physics
Specific problem: The district heating factory is facing high CO2eq emissions in the surrounding environment and general employee discontent with working conditions.
Challenge: Develop a precision environmental control system that optimises the condition within rooms for employees and climate change issues, improving green footprint and health outcomes.

Broad area: Healthcare
Specific problem: Elderly patients experience loneliness in hospitals.
Challenge: Create a solution to reduce feelings of loneliness among elderly hospital patients.

Make sure the challenge is achievable within the given timeframe and resources and remember it may evolve as students learn more about the problem - you can also push them to explore the challenge and edit it according to the results obtained from the need-finding phase (1.1.1 THE TRIPLE BOTTOM LINE: a multi-perspective process), since the process has a fundamentally iterative approach.

Directly engaging with potential users can help you find invaluable insights into their needs, frustrations and desires, as well as observing people in their natural environment can reveal hidden challenges and opportunities. To create the challenge, you can also gather industry data that can help you identify trends and consumer behaviour, or you can consult academic studies, news and media to remain updated with current events and emerging issues.

Furthermore, analysing successful design projects can inspire new challenges ideas:

- **Nielsen Norman Group:** This website offers expert insights into user experience and usability.
- **IDEO:** Known for its innovative design approach, IDEO shares case studies and methodologies.
- **Stanford d.school:** Offers resources and courses on design thinking.
- **HCD Institute:** Provides information and training on human-centred design.

By carefully considering your target audience, their specific needs and goals of your project, you can clearly understand which sources are more relevant and provide a unique project-based learning to your students.

INDUSTRY PARTNERSHIP

Collaborating with companies and public organisations can provide real-world challenges for students. This approach offers opportunities for authentic learning and potential career connections. The professor can establish a partnership with a company - that will present the challenge encountered in its organisation to students - and he must ensure the challenge is suitable for the course objectives.

2.3 SUPPORTING TOOLS FOR EFFECTIVE IMPLEMENTATION

This section introduces all the resources included at the end of this manual (appendix) to support your successful implementation of Design Thinking (DT) within your STEM courses using project-based learning. These tools are designed to deal with various teaching styles and student needs, allowing you to tailor your approach based on your teaching modality, course content and students. Experiment and explore to find and select the resources that seem most effectively and suitable for your course and students.

2.3.1 PRESENTATION SLIDES

A comprehensive presentation slide deck allows you to introduce DT to your students in a clear and engaging manner. Every deck of slides refers to a specific Milestone and is then relevant to the lesson it is referring to. As a professor, you can use these slides as a tool that helps you to introduce the PBL and the several techniques students are going to learn during your course.

2.3.2 MILESTONES FOR STUDENTS

Milestones serve as structured, step-by-step guidelines outlining the tasks to be completed by a specific deadline: these documents are aligned with the presentation slides discussed in the previous paragraph and will support you throughout the Project-based Learning activity. . For each stage of the project, a document is provided detailing the objectives students are expected to achieve within the given timeframe. These documents include a well-defined path and comprehensive descriptions of suggested tools and resources that are essential for the development and success of the project. Students may reference these milestone documents at any time to ensure they have clearly understood instructions and they're on the right way toward their final deliverables.

2.3.3 MIRO BOARDS

An online collaborative platform called Miro is included as a resource. Miro allows students to work together virtually, brainstorming ideas, visually organising project information, and creating mind maps in real-time. This fosters a collaborative learning environment and enhances communication within student teams. The board is thought to be used and edited by the team as it's dealing with the challenge, so that students will easily follow the structured process: its templates mirror the Milestones documents and Presentation slides provided and help students understand what and when to do the required tasks.

Here is the access to the Miro Board:
https://miro.com/app/board/uXjVLPnybPY=/?share_link_id=453446907949

2.4 OPERATIONAL GUIDE - cultivating student success in project-based learning

This section equips you with the tools and strategies to create a supportive and productive learning environment for your course. Here we are going to dive into group formation, student management throughout the project lifecycle and effective evaluation methods. Understanding the student experience is the cornerstone of exploring potential challenges and guiding students towards successful resolution.

2.4.1 BUILDING BALANCED TEAMS

"When people interact in a positive way, energy is not dissipated and differences are valued as opportunities to learn." (Hills, 2001)

The composition of your student groups significantly impacts project success. Teams work well in optimistic environments and when personalities clash, energy is spent in unproductive behaviour and no value is placed on diversity. This is the main reason why professors should focus on understanding the interplay between students in order to create high-performance teams.

Here are some key points to take in account while creating balanced teams:

- **Skills and learning styles**: pursuing diversity in skills, backgrounds and learning styles will foster a richer learning experience through collaboration and knowledge exchange. Consider creating teams in which strong research abilities, analytical skills, creative problem-solving approaches and excellent communication skills coexist.
- **Personalities**: consider a mix of personalities to ensure balance of ideas and approaches. While some students excel at brainstorming sessions and leading discussions, some others may be more profitable in data analysis, organisation and technical expertise.
- **Student preferences**: instructor-assigned groups can be effective but, whenever possible, incorporating student preferences can increase motivation and team dynamics. Therefore, use surveys or short questionnaires to take into account student preferences on a particular argument to work on.

Remember to build teams that can include various skills and knowledge: in these kinds of projects based on Design Thinking techniques, 4 up to 6 members as team size is really recommended to manage groups in a proper way.

To further help your students analyse themselves, here's a little DT mindset survey they can submit: https://designthinkingmindset.unibo.it/

2.4.2 MANAGING STUDENTS THROUGHOUT THE PROJECT JOURNEY

Students are the driving force behind successful PBL courses. To ensure their optimal experience, we are introducing some useful concepts:

- **Setting clear expectations**: clear outline project goals, timelines, deliverables and evaluation criteria since the beginning. This provides a roadmap for students and promotes a right direction to follow. Consider creating a project charter document that summarises these instructions and acts as reference for student teams.
- **Open communication**: establish open communication channels to address student doubts and concerns and provide prompt feedback during project development. Encourage students to share questions, roadblocks or emerging challenges with the class by using online discussion forums, dedicated project check-in sessions or classroom hours to facilitate communication.
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- **Identifying and addressing challenges**: Be prepared to identify and deal with common challenges such as time management, group conflicts or lack of clarity on specific tasks. Offer a point of reference for conflict resolution strategies and support mechanisms to help students overcome obstacles. Remember to provide resources on time management techniques and communication strategies for solving group conflicts and facilitating peer mediation.

2.4.3 EVALUATION: STUDENT REFLECTION ON THE EXPERIENTIAL LEARNING

Evaluating student learning in this kind of project requires student individual reflection on the experiential learning in order to develop a solution oriented mindset on a real-world challenge and build on the different serendipitous learning outcomes that arose along the process.

Experiential learning, as proposed by Kolb in 1984 is one of the most effective methods of learning. It allows for serendipitous discoveries throughout the process and provides learners with first-hand experiences in practical, contextualised settings (Kolb, 1984). However, the theorist emphasises that experiential learning is only effective when learners reflect on their experiences, enabling them to abstract and generalise learning points for application in diverse contexts.

Providing students with a framework for effective reflection is crucial to the learning process. This practice also contributes to the development of "learning to learn" competence, one of the eight key competencies of non-formal education proposed by the European Commission's framework.

Since reflection is an ongoing process that becomes more effective with frequency and depth, we have developed reflective diaries (templates are given as “Tools”) based on the Gibbs (1988) model for each of our two courses. These diaries provide a structured framework and guiding questions to help learners reflect on their experiences.

We recommend basing a component of your evaluation on reflection. To support this, we have developed guidelines for students to create a final reflection deliverable for the course. This approach allows you to evaluate how well learners have capitalised on their experiences for personal growth, rather than assessing general performance, which can be challenging to define in experiential learning where each student undergoes a unique experience.

Variety - Evaluate the range of aspects the learner has included in their reflection. Examples may include:

- content of the challenge;
- application of theoretical concepts in real-world contexts;
- time management throughout the process;
- engagement and collaboration with peers;

Depth - Assess how thoroughly the learner has reflected on each aspect presented:

- Have they provided specific examples to support their reflections?
- Have they abstracted and generalised their conclusions?
- Have they considered how to apply their learnings in future situations?

Relevance - Determine the applicability of the reflected aspects to the student's professional life:

- Has the learner connected their reflections to the course content?
- Have they built upon the theoretical material and frameworks provided during the course?
- Are their insights relevant to their future professional development?

CONCLUSION

Abstract

In this final chapter there's a summary of what has been discussed throughout the manual, from the Design Thinking methodology and its benefits to the students' learning outcomes and future developments, going through a brief recap of the two typologies of STEM courses we've identified. At the end of the manual there will be collected all the supporting tools provided to professors to allow them to introduce the Design Thinking techniques into their courses.

II.I KEY INSIGHTS FOR APPLYING DT IN STEM COURSES

The integration of Design Thinking (DT) into STEM education will lead students to achieve significant learning outcomes. The methodology has shown numerous benefits; depending on the type of course, technical or science-based, they manage to deal with the specific discipline with a human-centred and iterative problem-solving approach, improving their soft skills and developing the right mindset to make their way in the professional world. Here are the key insights for applying DT in STEM courses.

Enhancing Problem-Solving through User-Centred Approaches
One of the core insights has been the effectiveness of DT's user-centred approach in shifting students' mindset from purely technical problem-solving or theoretical assimilation to more holistic thinking. STEM students are traditionally trained to focus on technical accuracy, yet Design Thinking encourages them to step back and have a look at the bigger picture, taking into account real-word issues and considering the needs, behaviours, and emotions of the users, adding layers of empathy and creativity to the problem-solving process. In technical-based courses, for example, this has resulted in innovative designs that are not only technically sound but also highly user-friendly.

Boosting Creativity and Critical Thinking
By integrating the stages of Design Thinking—empathise, define, ideate, prototype, and test—students are forced to think more divergently, which is essential in tackling wicked challenges in STEM. The iterative nature of DT encourages students to treat failure as an opportunity for learning, making the

process highly dynamic and adaptive. This shift has been particularly valuable in courses where students are traditionally attracted by rigid, predefined solutions.

Multidisciplinary Collaboration and Team Dynamics
Collaboration across disciplines has proven to be a significant advantage. In project-based learning (PBL) settings, multidisciplinary teams bring together diverse expertise, which is particularly beneficial. The importance of balanced teams, where students come from different backgrounds and provide several Points Of View, has emerged as a critical factor in project success.
However, challenges in managing these teams, particularly in communication and aligning priorities, highlight areas for further refinement, including more structured team-building exercises at the outset of projects.

Impact on Professional Readiness
Design Thinking's iterative process mirrors the cycles of innovation found in professional STEM industries, making students better prepared for real-world challenges. The ability to take feedback, refine solutions, and adapt to changing circumstances enhances their attitude in needfinding and pretotyping phases and their professional readiness, especially in engineeristic and design fields.

II.II SCIENCE AND TECHNICAL-BASED COURSES: learning outcomes

Incorporating Project-Based Learning (PBL) with Design Thinking (DT) into STEM courses fosters a range of essential learning outcomes that enhance students' problem-solving, collaboration, and critical thinking skills.

- **Problem-Solving Skills**: Students learn to approach complex problems creatively, using iterative thinking to explore multiple solutions before reaching a conclusion.
- **Collaboration and Teamwork**: PBL with Design Thinking fosters a collaborative environment, encouraging students to work in diverse teams and value cross-disciplinary input.
- **Critical Thinking and Reflection**: Regular reflection, a key aspect of DT, helps students critically analyse their approaches, assumptions, and results.
- **Empathy and User-Centred Approach**: Students develop an understanding of the importance of end-users, learning to create solutions that meet real-world needs rather than purely theoretical models.
- **Adaptability and Resilience**: Students gain resilience through the iterative process of design, where failure is reframed as a learning opportunity rather than a setback.

While STEM disciplines share common ground, we thought it important to distinguish between science-based and technical-based courses. This understanding is crucial for professors as it informs how Design Thinking (DT) methodologies can be applied effectively in each type of course and the different learning outcomes students will achieve.

TECHNICAL-BASED STEM COURSES: LEARNING OUTCOMES

Technical-based courses typically involve engineering, computer science, and applied mathematics, where the focus is on delivering functional, optimised, and often tangible products or systems. Students will gain hands-on experience with rapid prototyping, system optimization, and practical application of their technical knowledge. This approach enhances their ability to design, test, and refine complex systems, while also improving technical communication skills as they present their solutions to both peers and external stakeholders.

- **Practical Application of Technical Skills**: Students improve their technical skills through the application of theoretical knowledge to real-world projects (e.g., coding, circuit design, robotics, etc.).
- **Systems Thinking**: PBL in technical fields fosters the ability to think holistically about systems, understanding the interconnectedness of components.
- **Prototyping and Iteration**: The hands-on nature of Design Thinking encourages rapid prototyping, testing, and refining of designs, which is crucial in fields like engineering or software development.
- **Efficiency and Optimization**: Emphasises designing solutions that are not only functional but also efficient, optimised for real-world constraints like cost, time, and resources.
- **Technical Communication**: Presenting technical solutions to both technical and non-technical stakeholders is crucial, developing students' ability to clearly explain complex systems.

SCIENCE-BASED STEM COURSES: LEARNING OUTCOMES

For science-based courses, the focus shifts toward inquiry-based research, where students apply the scientific method in a structured, iterative manner. They will develop stronger data interpretation and research skills, gaining the ability to test hypotheses and integrate theoretical concepts into practical experiments. Both course types emphasise the importance of adaptability, empathy, and collaboration, but with different focal points: technical students on efficient, functional solutions, and science students on research-driven exploration and societal impact.

- **Inquiry-Based Research**: Students engage in research-based problem-solving, where Design Thinking helps structure experiments, hypotheses testing, and exploration.
- **Scientific Literacy and Data Interpretation**: Students improve their ability to collect, analyse, and interpret data, often leading to evidence-based solutions.
- **Hypothesis Development and Testing**: The iterative nature of Design Thinking is aligned with the scientific method, reinforcing the importance of hypothesis development, testing, and refining theories.
- **Integration of Theoretical Knowledge**: Students apply theoretical concepts in a practical context, enhancing their understanding of scientific principles and laws.
- **Ethical and Societal Impact**: Science-based projects often involve considerations of ethical implications and societal impact, fostering awareness of how scientific solutions can affect communities and ecosystems.

ANNEX

BUILDING BALANCED TEAMS SURVEY

This survey aims to help us create effective project teams for the upcoming [project name] project. Your honest response will allow us to form balanced teams with a variety of skills, perspectives and experiences.

Section 1: IDENTITY

- How old are you? _____

- Where are you from? _____

- Are you currently working full-time or part-time?

a) No
b) Full-time
c) Part-time

Section 2: EDUCATIONAL BACKGROUND

- Previous field of studies (if applicable):

  a) Engineering;
  b) Computer Science;
  c) Mathematic;
  d) Chemistry;
  e) Biology;
  f) Physics;
  g) Ecology;
  h) Data Science;
  i) Robotics;
  j) Other (please, specify): _____.

- Current field of studies (if students from different degree courses are attending the course): _____

- What is your preferred learning style?

  a) Hands-on activities and experiments;
  b) Reading and research;
  c) Discussions and group work;
  d) Visual Learning (diagrams, charts, etc.);

Section 3: SKILLS AND PERSONALITY

- How would you describe your personality on a scale of 1 to 5? (1 = Introverted, 5 = Extroverted)

- If you are requested to describe yourself with three adjectives, what would they be? (e.g. Creative, Analytical, Collaborative) _____, _____, _____.

- How comfortable are you working independently on tasks? (1 = Not comfortable, 5 = Very comfortable)

- How well do you handle working under pressure? (1= Not well, 5 = Very well)

- Which of the following skills do you feel most confident in?

  a) Research and analysis;
  b) Writing and communication;
  c) Problem-solving and critical thinking;
  d) Project management and organisation;
  e) Technology and software proficiency;

- In your own words, what are you most interested in learning about through this project? ___________.

Section 4: MINDSET

- Are you familiar with the Design Thinking approach to problem-solving?

  a) Yes
  b) No

- Do you believe your skills and abilities can develop through learning and effort?

  a) Yes
  b) No

- In your own words, describe your biggest strength when working on a team project.

  ________________________.

- In your own words, describe an area where you would like to improve when working on a team project.

  ________________________.

Section 5 (Optional)

- Do you have any prior experience in the following areas related to the project?

  a) [Area 1];
  b) [Area 2];
  c) [Area 3];
  d) None of the above;

- In which of the following topics are you more interested in? Please, select your preferences here (you can select more than one option):

  a) [Option 1];
  b) [Option 2];
  c) [Option 3];
  d) None of the above.

Thank you for your participation!

ADDITIONAL NOTES

- Consider one of the suggested sections depending on whether the project requires specific information for creating balanced teams. You can also use all of them or a combination of them;
- Adjust the multiple-choice options to better align with the specific skills and knowledge required for your project.
- Remember to build teams that can include various skills and knowledge: in these kinds of projects based on Design Thinking techniques, 5 up to 7 members as team size is really recommended to manage groups in a proper way.
- Try to collect all the student responses in an Excel Table to facilitate your task: use colours to evidence commonalities and aim for colourful teams!
- To further help your students analyse themselves, here's a little DT mindset survey they can submit: https://designthinkingmindset.unibo.it/

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