

UNLOCKING SYSTEMATIC INNOVATION: ASSESSING THE IMPACT OF DESIGN METHODS IN UNIVERSITY-INDUSTRY COLLABORATION FOR OPEN CHALLENGES

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Abstract

Open innovation challenges connect companies and universities, while accelerating product development and achieving better market reach. Research has shown that these benefits are more consistent when the idea-generation process is based on proven methodologies within a sustainable business model.

Our study aims to measure the effectiveness of problem-solving methods in the development of value-added solutions for open innovation challenges, under the hypothesis that structured methods allow designing value-added solutions that can be transferred to the market.

To test it, we developed an experiment through two open innovation platforms, Agorize and Lions Up, using the challenges of two companies, Bayer and ENEL. A total of 187 students from two Chilean universities had to explore “how digital will Bayer be in 2032?” and design “solutions for the development of more efficient, livable and sustainable urban environments, building future Smart cities in Chile”, working with TRIZ, SCAMPER, and Design thinking.

The evaluation of the solutions considered three criteria, one from each company and an academic one. The teams that used TRIZ showed better results in both challenges, especially in the feasibility and transfer to the market possibilities. Design thinking had the lowest overall score, but improved significantly when used by more experienced students, showing the relevance of accumulated knowledge when working with intuitive methods.

Minor differences were identified among evaluation teams, which shows the importance of defining objective evaluation criteria. Finally, a relevant step is to investigate the reasons behind the lack of correlation between popularity and performance of design methods.

Keywords – SCAMPER, TRIZ, Design thinking, Open innovation, Business model canvas.

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1. Introduction

In today's business and technological landscape, the ability to innovate in an open and collaborative manner has become a critical factor for competitiveness. Open innovation, defined as *the deliberate use of internal and external knowledge flows to accelerate innovation* (Chesbrough & Bogers, 2014) enables organisations to leverage external resources -such as collaborations with universities- to solve complex problems and create viable market-transferable solutions. However, one of the main challenges in this context is identifying and evaluating which design method is most effective for addressing these initiatives, especially in environments characterized by high uncertainty and diverse participants (Murga-Pinillos, 2024; Torres-Benoni & Durán-Novoa, 2023).

The literature recognises the existence of various design methods, such as SCAMPER, TRIZ, and Design Thinking, each with specific strengths and limitations. For instance, methods like SCAMPER and TRIZ guide the ideation process through systematic principles, enhancing the feasibility and quality of solutions (Duran-Novoa et al., 2019; Duran-Novoa & Torres-Benoni, 2024). In contrast, approaches like Design Thinking often rely heavily on the prior experience of designers, which can limit their effectiveness in contexts where participants have heterogeneous levels of knowledge (Baban et al., 2021; Murga-Pinillos, 2024).

Despite advances in understanding how these methods can influence the success of open innovation, significant research gaps persist. There is a need for objective and replicable evaluations that allow for the comparison of different design methods based on key criteria such as novelty, quality, feasibility, and market transferability (Duran-Novoa et al., 2019; Torres-Benoni & Durán-Novoa, 2023). Such evaluations are essential not only for optimizing educational processes in design and innovation but also for informing the selection of methods in business settings aiming to maximise the return on their open innovation initiatives (Murga-Pinillos, 2024).

This study seeks to address this need by comparing different design methods applied in the context of open innovation challenges posed by global companies. By evaluating the results generated by students and professionals, this work aims to identify which design method is most effective for producing viable, market-transferable solutions, thereby contributing to the development of theoretical and practical frameworks that advance university-industry collaboration.

1.1. Hypothesis

It is essential to evaluate the results of the innovation process during the early stages of design to quantify its market transfer potential. However, measuring this potential can be challenging due to the uncertainties associated with both technical aspects and market conditions. Also, technology projects often target uncertain markets with less defined value propositions (Bogers et al., 2016; Durst & Stähle, 2013; Gassmann et al., 2010). The evaluation of solutions tends to be favored when they are assessed using multiple criteria to determine their potential transfer to the market, while including design methods allows to compare among studies and potentially determine the impact.

Our hypothesis is that design methods enable the development of value-added solutions that can be transferred to the market (market-ready). Previous studies do not specify whether the method used in the design of the solution modifies the results, so this factor could be relevant in Open innovation processes (Baban et al., 2021; Chesbrough et al., 2006; Murga-Pinillos, 2024; Osorno-Hinojosa et al., 2022).

To test this hypothesis, we conducted two experiments using open innovation platforms, Agorize and Lions Up; the effectiveness of design methods in open innovation challenges was quantified using three main criteria: academic, business development, and teamwork. Finally, one of the open innovation challenges proposes awards, which will allow to observe how this factor could affect the proposal.

2. Literature Review

2.1. Open Innovation

Open innovation (OI) is mostly defined by interactions across organisational boundaries, being somehow the opposite to traditional research and development, which tends to be carried out within specific company departments. In our study, we consider OI as “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and to expand the markets for external use of innovation, respectively.” (Huizingh, 2011). Its processes are usually segmented into laboratory stages (idea generation) and market (feasibility of being transferred) (Gassmann et al., 2010). Literature shows a wide list of research topics, characterised by the content and process of OI (Huizingh, 2011), the exploration in the OI front-end and the role of technologies (Brunswicker et al., 2012), the classification of OI literature into the firm perspective and ecosystem perspective (Remneland-Wikhamn & Wikhamn, 2013), the inbound processes of OI (West & Bogers, 2014), performance of OI, role of venture capital in the OI system (Bigliardi et al., 2020), and the definition of the openness construct (Dahlander et al., 2021). In general, the most frequent and relevant topics were *context dependency of OI*, *collaborative frameworks*, and *external search for OI and technology*. Table 1 presents various initiatives around OI.

Type	Description
Universities	It allows access to numerous researchers and students. This characteristic is amplified in the case of projects with consortia in which private companies and universities participate (Chesbrough et al., 2006). Universities, providers, and consumers represent the largest volume of access to knowledge (Aslesen & Freel, 2012).
OI intermediaries	Service providers who offer planning, execution, and operation of OI projects. OI intermediaries strengthen information flows (Randhawa et al., 2017).
Cross-Industry Innovation	The goal is to identify, adapt and transfer solutions from other industries. Proven technologies reduce the technical risk of the solution.(Enkel & Gassmann, 2010).
Idea platform	An idea-platform does not have a defined duration as in an ideas contest. Therefore, ideas can be submitted permanently (Sloane, 2011).
Idea contest	An assignment is presented to the public. Depending on the configuration of the contest, the participants submit their ideas, being able to evaluate the ideas of other participants. The idea with the highest rating is rewarded with a prize (Walcher, 2007).

Table 1. Types of collaborations in OI

Theoretically, competency-driven innovation increases the potential for innovation because ideas come from a greater interaction of people sharing and transferring information, which can keep growing as innovative ecosystems that are more likely to develop and integrate. In general, they have three main benefits, a unique innovation mechanism away from parent industry constraints, an agile environment that can increase innovation development, and a return pathway for adoption back to the parent industry (Jensen, 2021). However, there are several limiting factors, mostly related to people interaction, community companies’ process, and strategy in general.

Community companies can be affected by ideas previously presented (by other people) or when there are certain constraints that force decisions to be made around the proposed solution idea. A similar effect is observed in communities of people who generate innovation, but who tend to generate similar ideas because of what is called the *network structure effect* (Stephen et al., 2016). Additionally, it has the same potential drawbacks that Brainstorming such as social inhibition, production blocking, social matching, evaluation apprehension, social loafing, and free riding (Hofstetter et al., 2021). Processes develop engagement mechanisms, coordinator constraints, quality assurance tradeoffs, time pressures, technological affordance, and security concerns. Finally, sharing information and transferring it does not ensure that the proposed solution ideas are of added value for the target market, which often is not aligned with organizational strategy; this means that the challenges seek solutions to real problems that cannot be solved within the framework of intra-mural innovation (and apparently not with IoT) can be

approached via OI models like open-source community, innovation marketplace, customer innovation, crowdsourcing, or social product development.

Within OI's, **it has not been investigated which design methods can improve the design process results.** In general, participants work intuitively around the challenges, while the main theories argue that the results in OI are improved by organizational factors (Yao et al., 2023), relationships between ideas provided to a crowd or diversity of examples given to a crowd (Malhotra & Kubowicz-Malhotra, 2023) or the perspective of feedback (negative or positive) to designers (Yang et al., 2023). OI challenges results have been studied in companies, obtaining analyses and conclusions mostly through interviews (Raya et al., 2021). The general conclusion is that OI has a positive effect, but how these results have been measured it is not declared, nor how they could improve their performance using alternative strategies or design methods during the innovation process (Aguirre et al., 2023). An opportunity is identified to evaluate the impact of design methods on the generation of business models, which could help to measure the effect of OI and the transfer of solutions to the market (Torres-Benoni & Durán-Novoa, 2023).

2.2. Design Methods and Evaluation Criteria

There are many definitions of what design methods are, generally related to design methods and value propositions. We will work with Oxman's definition of "*specific procedures to integrate, analyse, or evaluate the phenomenon of a design object. Applying a design method produces new design ideas based on the designer's previous knowledge* (Oxman, 2006)."

For the research's development, we have chosen four methods: Business model canvas (BMC), TRIZ (mostly the Contradiction Matrix), SCAMPER (SC), and Design Thinking (DT).

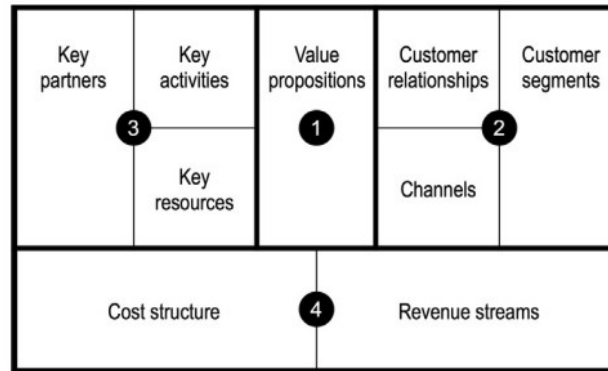
All students will use BMC as a common framework to structure their design proposal into solutions with potential to be transferred to the market. DT, TRIZ and SC, were selected mostly due previous research that will allow us to compare results and observe relevant differences. To evaluate the proposals and measure the methods' effect in the added-value, multiple variables like innovation factors, business, teamwork, leadership, and value proposition should be considered (Duran-Novoa & Torres-Benoni, 2024; Torres-Benoni & Durán-Novoa, 2023). In our work, we group the evaluation criteria in three categories, Academic (Innovation), Business Development, and Teamwork (details in Section 2.3).

2.2.1. Business Model Canvas

Business Model Canvas (BMC) is a strategic management template used for developing new business models and documenting existing ones, which is commonly used in various contexts and can be easily adapted for the analysis of different kinds of projects (Link, 2016; Nidagundi & Novickis, 2016). It is commonly used in entrepreneurship projects, where the degrees of uncertainty are higher, resembling the degrees of uncertainty of OI's challenge. Looking at the effect of design methods on business model design should allow to explore the relevance of completing design methods with the canvas tight (Sire et al., 2019).

BMC framework consists of nine interrelated blocks, which contains four key development factors: customer interface, product (solution), infrastructure management and financial aspects (Keane et al., 2018; Osterwalder et al., 2014) The use of BMC in the early design stages is constituted as a "prototype" of the business model, which could be iterated based on changes in market variables, the need, the value proposition and the capabilities to transfer to the market a sustainable solution (Link, 2016). Although it is mostly used in entrepreneurial projects, it is frequently observed in established companies (Keane et al., 2018).

BMC will be used as a cross-cutting method for all teams, becoming a common starting point- that levels the basic structure of design methods, minimising potential "holes" or "barricades" that could delay or stop teams' projects development (see Figure 1). Participants will present models of nine canvas blocks to present their business model strategy and consequently measure whether the solutions are transferable to the market, estimating also if their value proposition can be maintained over time.



Note: 1= Product; 2 Customer interface; 3= Infrastructure management; and 4=Financial aspects.

Figure 1. Conceptual representation of the BMC (Keane et al., 2018)

2.2.2. The TRIZ Contradiction Matrix (MaTriz)

The Theory of Inventive Problem Solving (TRIZ) proposes that all inventions are based on universal principles that can be identified and codified to make the inventive process more predictable (Cascini & Rissone, 2004; Duran-Novoa et al., 2011; Kudrowitz & Wallace, 2013; Mann, 2009; Zhang & Liang, 2007). Problems are isolated and presented as contradictions to identify inventive principles that have the potential to be adapted and become a realistic solution to the problem (see Figure 2). TRIZ was chosen because there are previous studies that can be used to compare results, where it has shown better results in multicriteria evaluations (Duran-Novoa & Torres-Benoni, 2024). The use of TRIZ in engineering education processes is relatively more sophisticated in its implementation, but at the same time offers better results in design processes (Belski, 2009; Belski et al., 2013; Berdonosov, 2015; Cavallucci & Oget, 2013; Lepeshev et al., 2013).

We will work using two of 'TRIZ' multiple tools, the Mini-problem and the Contradiction matrix (MaTriz). The MaTriz has the advantage that it forces the correct use of TRIZ's basic principles (See Figure 2).

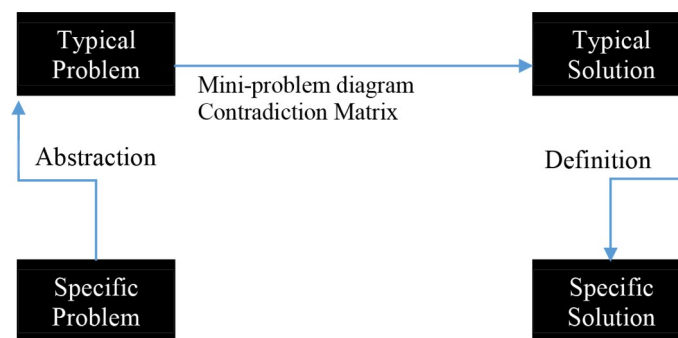


Figure 2. Adapted from *Inventing Problem Solving* (Duran-Novoa et al., 2011)

2.2.3. SCAMPER

SCAMPER is a mnemonic that stands for Substitute, Combine, Adapt, Modify, Reuse, Delete, and Revert (Eberle, 2008). It was proposed by Alex Osborn as the Scamper method and later denominated the SCAMPER Technique (Eberle, 1996; Serrat, 2017). The method establishes an algorithm structure for problem-solving, in which the categories delimit the search areas. The user analyses the problem or its parts, considering the seven principles to stimulate creative ideas for improvement or new developments (Serrat, 2017).

As TRIZ, in previous studies SCAMPER users performed better than the average of participants (Duran-Novoa et al., 2019; Gero et al., 2013). Its ease of use favors its application in different contexts.

In this article, SCAMPER will be classified as an algorithm for problem-solving, in which categories delimit the search areas for the resolution of a problem. In simple terms, the user analyses the problem or its parts, considering the seven principles to stimulate creative ideas for improvement or new developments.

2.2.4. Design Thinking

Design thinking studies focus on its use as a cognitive style, a general theory of design, and a resource for organisations. Extensive application is noted among educators, design consultants, and academics (Kimbell, 2011, 2012). We chose it for its popularity and recognition as a facilitator of innovation processes in both business and educational settings (Dorst, 2011; Dym et al., 2005).

Teaching DT to students fosters a broader creative process, particularly when developed in team settings, making it a valuable tool for solution design learning contexts (Dym et al., 2005). However, while DT can be beneficial, the best results in the creative process often stem from the experience of the team or individual members, not solely from the application of DT itself (García-Manilla et al., 2019). Moreover, the distinction between expert and novice design thinkers plays a crucial role in problem-solving approaches. Expert design thinkers analyse problems holistically and visualise them directly, while novices tend to explore solutions sequentially with less analysis (Razzouk & Shute, 2012).

In practice, teams will conceptualise problems using the focus question “How could we?”, a characteristic that will be compared to the SCAMPER and TRIZ processes. They will employ tools like empathy maps, concept maps, and drawings to present their solutions. The structured nature of these tools suggests that DT may yield better results compared to more intuitive methods like brainstorming and the KJ-technique, as observed in previous studies.

2.3. Evaluation Criteria: Academic, Business Development and Teamwork

Among the key factors in innovation processes are its configuration and its evaluation mode. While a variety of evaluation criteria exist, three variables consistently emerge as the most frequent: novelty, feasibility and effectiveness (Besemer, 2000; Cooper, 1992; Byttebier, 2012; Van Der Meer, 2007).

This study applied three macro-evaluation criteria, one from academic works, and two from the open innovation challenges: the Bayer-Agorize evaluation criterion, and the Enel-Lions UP criterion (see section 3.1.1).

2.3.1. Academic (Innovation). (Criterion 1)

Previous studies show a diversity of evaluation methods that do not allow an adequate comparison, and therefore their objectivity can be objected (Duran-Novoa et al., 2019). An opportunity is observed in adapting Nelson’s criteria, which measure novelty, variety and quality (Nelson et al., 2009); on it, different levels of assessment will be established so that these results can be compared with previous studies. Each variable was assessed on a 5-point scale, ranging from 0 to 4, with a potential score of 12 points for a proposal.

2.3.2. Business Development (Criterion 2)

The business criterion was proposed by Bayer-Agorize, for which the same scales of the innovation criterion (0 to 4) were defined. It measures innovation potential, customer focus, economic impact/efficiency, and pitch (presentation). The Bayer-Agorize criteria is a validation mechanism used by a global company, where the value proposition understood as innovation, business model, development potential and mode of presentation are constituted in relevant factors; complementarily, previous studies shows results of measurement of innovation processes from the perspective of venture capital or measurement of solutions in contexts of open innovation between companies (Katsikis et al., 2016; Knight, 2013).

Each variable was assessed on a 5-point scale, ranging from 0 to 4, with a potential score of 16 points for a proposal.

2.3.3. Teamwork (Criterion 3)

This criterion has been proposed by Enel-Lions Up, and its oriented to measure the entrepreneurial skills of participants, which we have considered as a complement to the two previous criteria. The variables to be measured are characterisation of the user, definition of the problem, solution of the idea, communication, and teamwork. Skills and abilities for teamwork are key factors in developing solutions, especially in open innovation contexts (Chan et al., 2017; Chatenier et al., 2010; Oh & Choi, 2020). Each variable was assessed on a 5-point scale, ranging from 0 to 4, with a potential score of 20 points for a proposal.

3. Methodology

As defined in section 2.1 Open Innovation is “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and to expand the markets for external use of innovation, respectively.” (Huizingh, 2011). However, measuring the relevance of the solution could be difficult considering the problem of technical and market uncertainty. This uncertainty increases with early-stage technology projects that are characterised by directing their value offer to uncertain markets (Chesbrough, 2016). Different evaluation criteria difficult results comparison, while evaluation through surveys and teams of experts are frequent.

The structure of this study focuses on the design method influence and attempts to separate it from the impact of the designer or the specific challenge in the obtained results (see Figure 3). The teams' proposals will be evaluated using three different criteria (academic, business development and teamwork). A qualitative methodology was employed, which has been observed and validated in previous studies that provide analyses of the educational process by applying methods and technologies, as well as by examining phenomena in primary and secondary education contexts (Alonso-García et al., 2024; Parra-González et al., 2020; Romero-García et al., 2024)

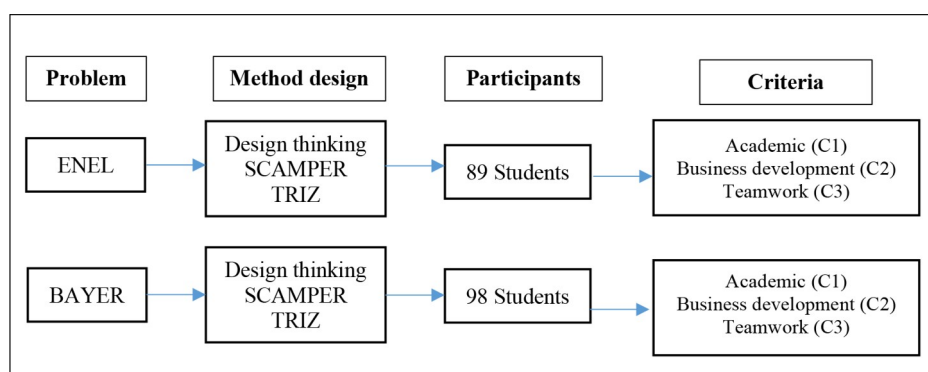


Figure 3. Research design

3.1. Sample and Procedure

The experiment was carried out with the participation of 187 students from two Chilean universities, USACH and UDD. Two innovation challenges were presented, one proposed by Bayer through the Agorize platform (AG), and the other by Enel through the Lions Up (LU) open innovation program. Three design methods were used, DT, SCAMPER and TRIZ. Teams of 3 to 5 people with students from different study areas and levels of knowledge were randomly assigned. Each team was assigned a design method, being trained in online streaming sessions. All teams received training in business model design, with an emphasis on developing a value proposition that can be transferred to the market (Table 2). Each team chose one of the 4 subsegments proposed in each challenge.

Regarding prior exposure to design methods, most participants had previous academic experience with SCAMPER and TRIZ, while DT was less familiar to them. This difference is relevant for interpreting the results and explains the need for additional instructional support in DT teams.

Challenge	Design Method	Business Model	Team (quantity)	Evaluation criteria (quantity)
AG	Design thinking	Canvas	16	3
AG	SCAMPER	Canvas	3	3
AG	TRIZ	Canvas	4	3
LU	Design thinking	Canvas	16	3
LU	SCAMPER	Canvas	4	3
LU	TRIZ	Canvas	3	3

Table 2. Teams assigned by challenge, method and evaluation

Both challenges were developed in 15 sessions of 60 minutes each. The implementation of DT differed from SCAMPER and TRIZ in that DT teams received structured mentoring sessions, while the other groups relied primarily on self-guided tutorials. This decision was made to compensate for the participants' lower prior familiarity with DT, as SCAMPER and TRIZ had been previously introduced in their academic training. Therefore, mentoring was incorporated as a levelling mechanism rather than an experimental advantage, aiming to ensure comparable baseline understanding across methods. All teams presented their solution ideas through digital presentations that included the basic value proposition and the prototype through conceptual sketches, mock-ups or diagrams (Table 3).

Stage	Enel LU			Bayer AG		
The challenge was presented	The challenge was presented by ENEL executives accompanied by the LU team of mentors. Questions about the development of the work sessions were answered and the objectives of the open innovation program were explained. ENEL challenge required designing solutions for the development of more efficient, livable and sustainable urban environments, building future Smart cities in Chile, through four pillars of development, decarbonization, electrification, digitization, and circular economy.			The Bayer challenge presents all the conditions of the challenge (including the prize for the winning team) through the Agorize website with an explanatory and detailed summary of the conditions and rules established for the presentation of solutions. Bayer challenge aimed to explore “how digital will Bayer be in 2032?”, posing four areas of development, namely data-driven farming, digital therapeutics, data science, and cyber security.		
Introduction to the assigned method	Design Thinking	SCAMPER	TRIZ	Design Thinking	SCAMPER	TRIZ
Method application	Empathy map	7 Principles	Mini problem diagram	Empathy map	7 Principles	Mini problem diagram
Mentoring	Yes	No	No	Yes	No	No
Present the user	Delivery of the progress status of the project	Delivery of the progress status of the project	Delivery of the progress status of the project	Delivery of the progress status of the project	Delivery of the progress status of the project	Delivery of the progress status of the project
Define the problem	Delivery of the progress status of the project	Delivery of the progress status of the project	Delivery of the progress status of the project	Delivery of the progress status of the project	Delivery of the progress status of the project	Delivery of the progress status of the project
Preview	Pitch 1	Delivery of the progress status of the project	Delivery of the progress status of the project	Pitch 1	Delivery of the progress status of the project	Delivery of the progress status of the project
Mentoring	Yes	No	No	Yes	No	No

Stage	Enel LU			Bayer AG		
	Yes	No	No	Yes	No	No
Mentoring	Yes	No	No	Yes	No	No
Teach business model	Value propositions (Canvas). Business model	Value propositions (Canvas). Business model	Value propositions (Canvas). Business model	Value propositions (Canvas). Business model	Value propositions (Canvas). Business model	Value propositions (Canvas). Business model
Mentoring	Yes	No	No	Yes	No	No
Preview	Pitch 2	Delivery of the progress status of the project	Delivery of the progress status of the project	Pitch 2	Delivery of the progress status of the project	Delivery of the progress status of the project
Mentoring	Yes	No	No	Yes	No	No
Mentoring	Yes	No	No	Yes	No	No
Final presentation of the project	Pitch 3	Pitch 1	Pitch 1	Pitch 3	Pitch 1	Pitch 1

Table 3. Method application procedure

3.1.1. Evaluation

The evaluation criteria used add up to a total of 12 variables (Figure 4). All variables were measured in a range from 0 to 4. The first criterion (Academic) measured novelty, variety and quality. The evaluation criteria proposed by Bayer-Agorize (Business Development) measures the variables of potential innovation, customer focus, economic impact (business plan) and presentation (pitch). The criterion proposed by Enel-Lions Up (Teamwork) measures the variables user, problem, idea, effective communication and teamwork (leadership).

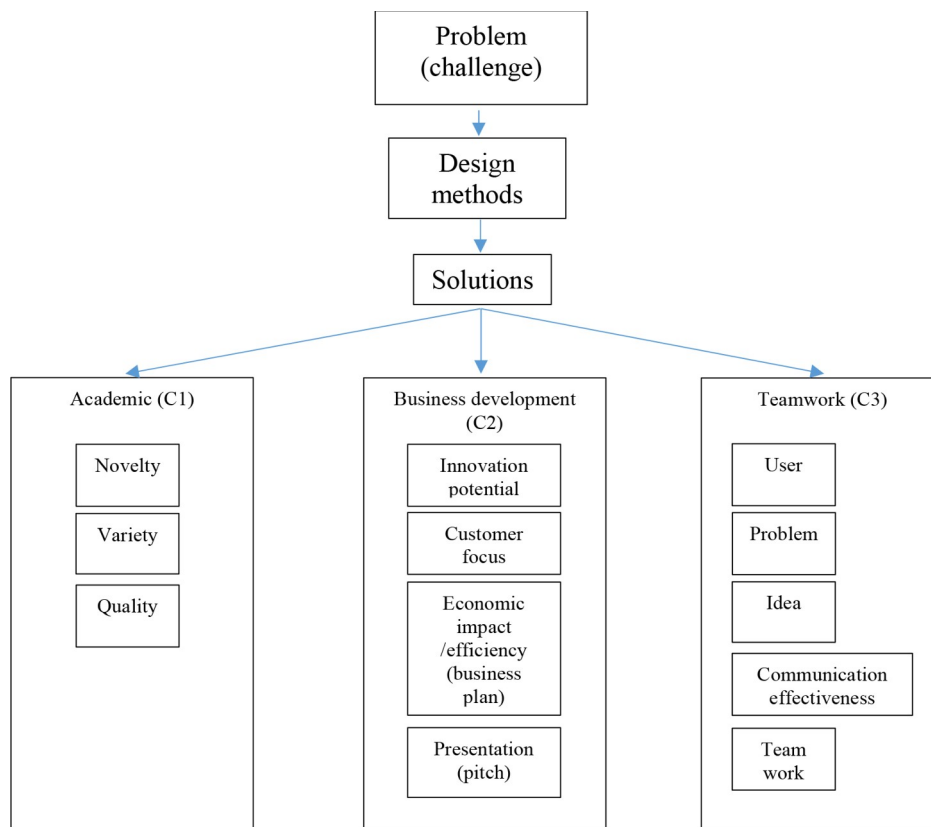


Figure 4. Evaluation criteria variables.

Each proposal was evaluated independently by three experts. After the initial individual assessments, evaluators discussed their scores to reach a consensus when significant discrepancies were identified. The final score for each variable corresponds to the agreed value after this reconciliation process, ensuring both individual judgment and collective validation. The results were subsequently analysed, compared with each other, and contrasted with previous studies. The Academic criterion is mainly aimed at measuring the new and disruptive components of the solution and does not consider commercial aspects. The Business development criterion includes business focused variables, putting emphasis on how the solution fits with the market demands. The last criterion, Teamwork, is oriented towards the human role in the problem analysis and solution. In this way, the comparison of the three criteria should allow us to obtain a wider, more objective analysis of the design methods (Figure 5).

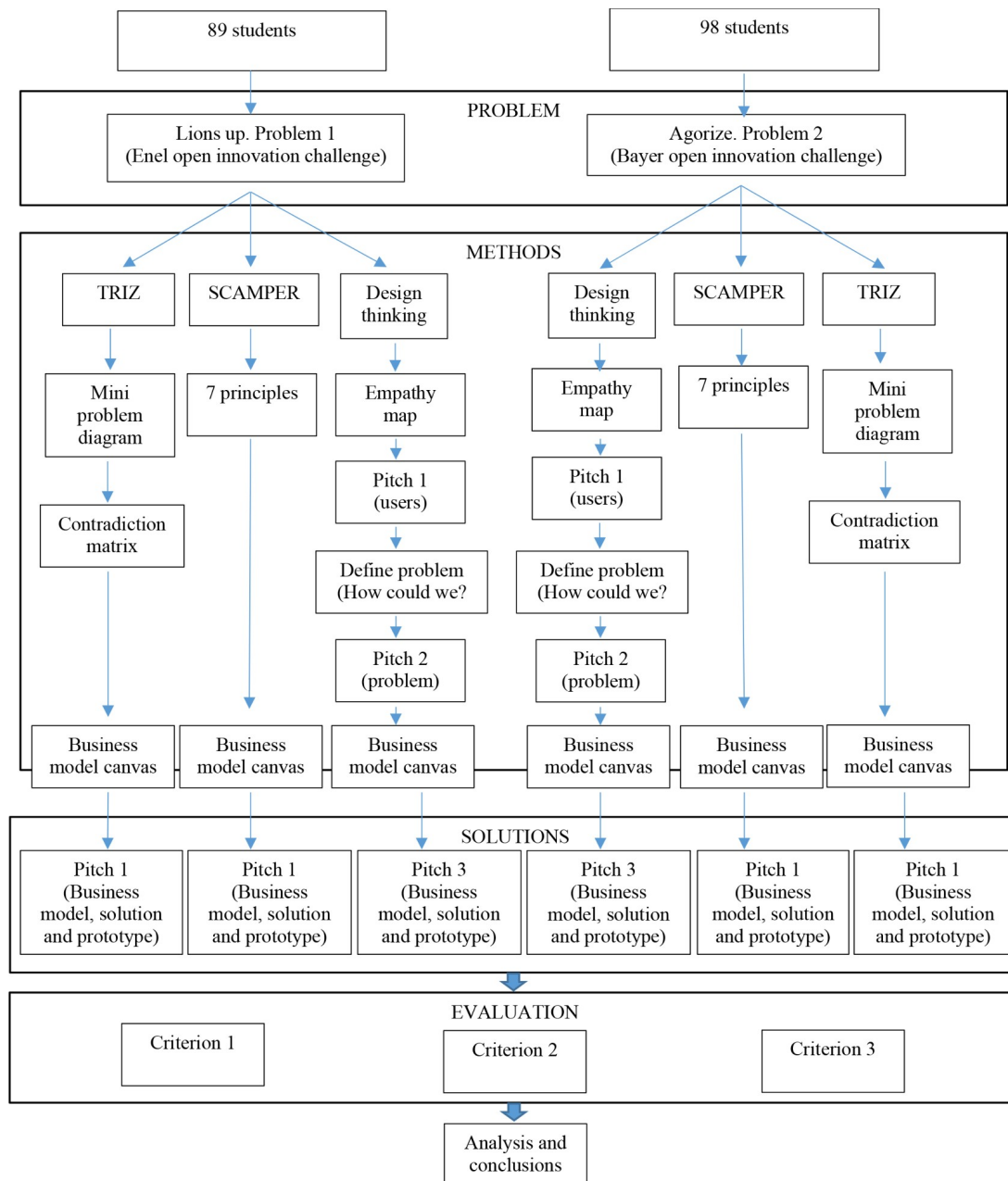


Figure 5. Design of experiments

4. Results

As explained in section 2.3, projects were evaluated following three criteria: *Academic* (from previous research), *Business development* (from Bayer), and *Teamwork* (from Enel).

4.1. Differences in Results Between Challenges (Tendencies Originated by the Challenges Nature)

Each challenge had relevant differences in focus, territorial scope, and areas of solutions development. Since methods were the same and participants have a similar background, it is expected that global results variances have its origin in challenges' specifics. A short list of differences is presented in Table 4.

Characteristic	Enel (Lions Up)	Bayer (Agorize)
Focus	Environment	Digitization
Territorial scope	Country	Worldwide
Solution scopes	Decarbonization, electrification, digitization, and circular economy	Data-driven farming, digital therapeutics, data science and cyber security
Follow up	Follow-up by the lions up team	Follow-up by the Agorize team
Communication	Virtual meetings	Agorize Open Innovation Platform and Teams

Table 4. Main differences between challenges

Globally, Enel's challenge scores were 6 % higher and less dispersed. The most notorious difference was observed in *Business development* (Criterion 2) with a 7.5 % difference. In general, each of the 12 variables had similar results in both challenges, being *Innovation potential* (Criterion 2) the exception, with a 22.5% difference (see Figure 6). This variable is the main cause of the score difference between/among challenges (see Table 5).

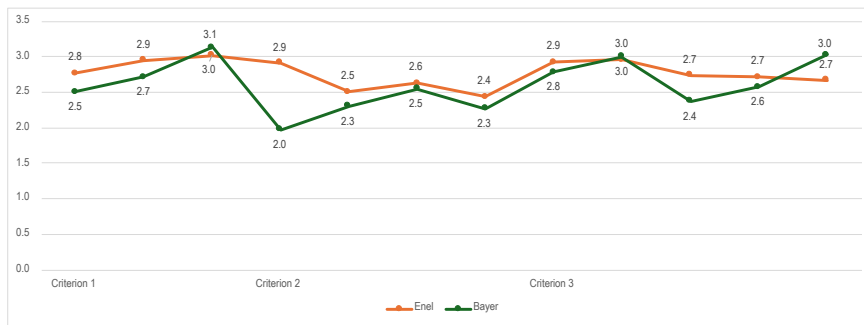


Figure 6. Global results, relative performance. Scores are based on a 0–4 scale for each variable, grouped into three criteria: Academic (C1), Business Development (C2), and Teamwork (C3).

Criteria	Method	Enel			Bayer		
		Design Thinking	SCAMPER	TRIZ	Design Thinking	SCAMPER	TRIZ
Criterion 1	Novelty	2.4	2.3	3.7	2.3	2.0	3.3
	Variety	2.8	2.8	3.3	2.3	2.3	3.5
	Quality	3.1	3.0	3.0	2.3	3.3	3.8
Criterion 2	Innovation potential	2.8	2.3	3.7	2.0	1.7	2.3
	Customer focus	2.3	2.3	3.0	1.8	2.3	2.8
	Economic impact/efficiency (business plan)	2.6	2.3	3.0	2.1	2.3	3.3
	Presentation/pitch	2.6	1.8	3.0	2.3	2.0	2.5
Criterion 3	User characterization	2.4	3.0	3.3	2.4	2.7	3.3
	Definition of the problem	2.4	2.5	4.0	2.5	3.0	3.5
	Idea solution	2.6	2.3	3.3	2.1	2.0	3.0
	Communication	2.6	2.3	3.3	2.6	2.7	2.5
	Teamwork	2.8	2.3	3.0	2.8	3.3	3.0

Table 5. Global results between challenges and design methods

4.1.1. Academic Results

As mentioned in section 2.3.1 the first criterion, *Academic*, is comprised of three variables, *novelty*, *variety*, and *quality*. On average, Enel’s challenge scores were 2.5% higher (see Figure 7). Bayer results were better in *quality* (idea feasibility, how easy is to implement it) and lower in novelty, independent of the method; in Enel, quality was almost identical, while TRIZ’s novelty and variety results balanced the average per variable (see Table 6).

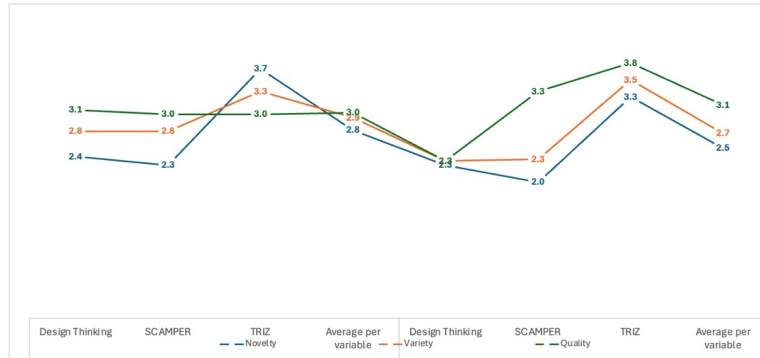


Figure 7. Bayer and Enel challenges performance by academic criterion. Scores are based on a 0–4 scale for each variable, grouped under an academic criterion (C1)

The comparatively better performance of TRIZ was observed in Enel’s *Novelty* and Bayer’s *Quality*, while in general, all methods presented a more balanced performance in Enel’s challenge (See Table 6).

Method	Enel				Bayer			
	Novelty	Variety	Quality	Average	Novelty	Variety	Quality	Average
Design Thinking	2.4	2.8	3.1	2.7	2.3	2.3	2.3	2.3
SCAMPER	2.3	2.8	3.0	2.7	2.0	2.3	3.3	2.6
TRIZ	3.7	3.3	3.0	3.3	3.3	3.5	3.8	3.5
Average per variable	2.8	2.9	3.0	2.9	2.5	2.7	3.1	2.8

Table 6. Enel and Bayer performance

4.1.2. Business Development Results

The second criterion, *Business development*, is comprised by four variables: *Innovation Potential*, *Customer Focus*, *Economic*, and *Pitch*. It is oriented to quantify how innovative and groundbreaking are the ideas. The general results were 7.5% better in Enel, highlighting that *Innovation Potential* was simultaneously Enel’s best and Bayer worst (2.0 vs. 2.9), being the cause of the results difference between challenges (see Figure 8).

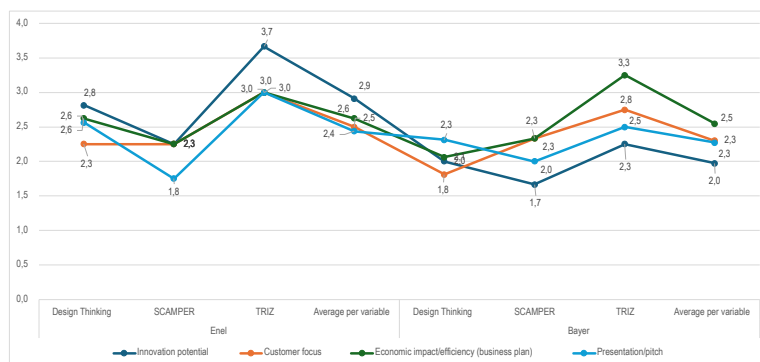


Figure 8. Challenge performance by business development criterion. Scores are based on a 0–4 scale for each variable, grouped under a Business Development criterion.

In both challenges, Triz performs better, while DT and Scamper have a similar performance in Bayer, but in ENEL DT performs consistently better (see Table 7).

Challenge	Method	Innovation potential	Customer focus	Economic impact/efficiency (business plan)	Presentation /pitch	Average
Bayer	Design Thinking	2.0	1.8	2.1	2.3	2.0
	SCAMPER	1.7	2.3	2.3	2.0	2.1
	TRIZ	2.3	2.8	3.3	2.5	2.7
	Average per variable	2.0	2.3	2.5	2.3	2.3
Enel	Design Thinking	2.8	2.3	2.6	2.6	2.6
	SCAMPER	2.3	2.3	2.3	1.8	2.1
	TRIZ	3.7	3.0	3.0	3.0	3.2
	Average per variable	2.9	2.5	2.6	2.4	2.6

Table 7. Performance in Bayer and Enel

4.1.3. Teamwork Results

The third criterion, *Teamwork*, focuses on leadership and teamwork. It is comprised of five variables: *Characterization of the user*, *Definition of the problem*, *Solution of the idea*, *Communication*, and *Teamwork*. Global results were similar in both challenges, although Bayer results were more disperse. *Definition* and *Teamwork* scored better in Bayer, while *Idea* was the weakest (15% difference).

It is important to note that *Idea* obtained better results in Enel (7.5%) with TRIZ performing better in all variables, which is consistent with Criterion 1 results (*Academic*) (see Table 8).

Challenge	Method	User characterization	Definition of the problem	Idea solution	Communication	Teamwork	Average
Bayer	Design Thinking	2.4	2.5	2.1	2.6	2.8	2.5
	SCAMPER	2.7	3.0	2.0	2.7	3.3	2.7
	TRIZ	3.3	3.5	3.0	2.5	3.0	3.1
	Average per variable	2.8	3.0	2.4	2.6	3.0	2.8
Enel	Design Thinking	2.4	2.4	2.6	2.6	2.8	2.6
	SCAMPER	3.0	2.5	2.3	2.3	2.3	2.5
	TRIZ	3.3	4.0	3.3	3.3	3.0	3.4
	Average per variable	2.9	3.0	2.7	2.7	2.7	2.8

Table 8. Bayer challenge performance

4.2. Differences in Performance Between Methods

This subsection presents a comparative analysis of the design methods' performance, considering both challenges. It is anticipated that the methods will retain certain characteristics across these challenges, such as superior performance in specific criteria. This consistency could support the notion that the method itself is the primary driver of the observed results.

Globally, DT and SC have a similar performance (average), having a notorious difference in Enel's challenge, criterion 2, where DT surpass SCAMPER by a 12.5%; TRIZ outperforms both in all criteria,

19% globally, obtaining an 80% of the maximum score possible (see Table 9). The relation between performance and each criterion shows a similar trend in all methods (see Figure 9).

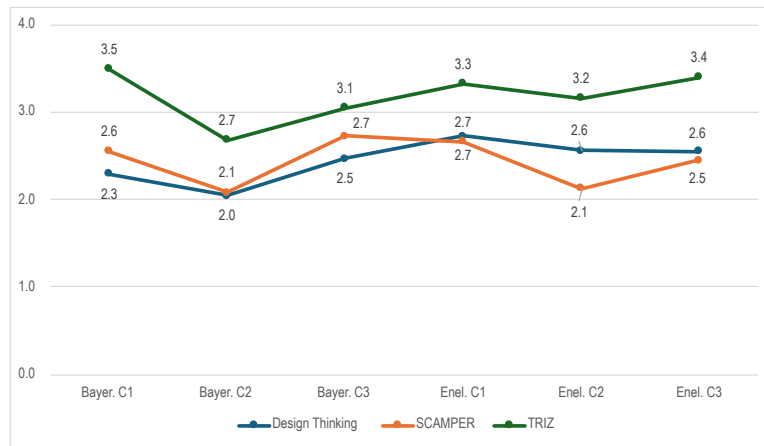


Figure 9 Average performance, by criterion

Method	Bayer C1	Bayer C2	Bayer C3	Enel C1	Enel C2	Enel C3	Total	% to max.
Design Thinking	2.3	2.0	2.5	2.7	2.6	2.6	14.7	61%
SCAMPER	2.6	2.1	2.7	2.7	2.1	2.5	14.6	61%
TRIZ	3.5	2.7	3.1	3.3	3.2	3.4	19.1	80%
Average	2.8	2.3	2.8	2.9	2.6	2.8	16.1	67%

Table 9. Bayer and Enel challenges performance

4.2.1. Criterion 1. Academic

TRIZ outperforms SCAMPER and DT on both challenges. In Enel’s challenge SCAMPER and DT have almost identical performance, while TRIZ results are 24% better than DT and 17% better than SCAMPER, mostly due to their difference in *Novelty* (see Figure 10), All methods have a similar performance in *Quality*, relating ENEL’s conditions to its feasibility (see Figure 10).

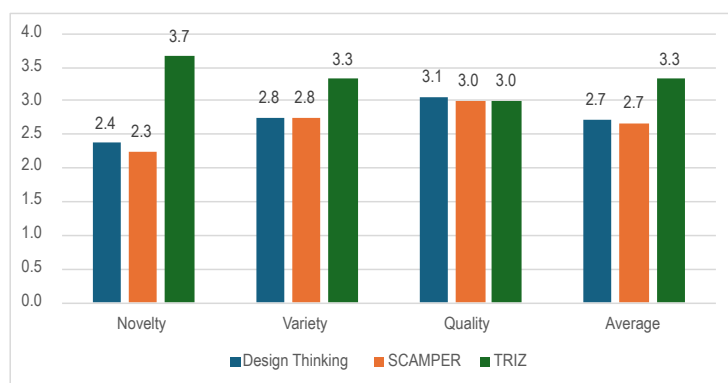


Figure 10. Performance of the methods for the innovation criterion (ENEL Challenge)

In Bayer’s challenge, TRIZ performs better in all variables. DT results are surprisingly low in *quality*, considering that they have the largest number of participants, which reduces the probability of specific individuals affecting the results; also this low result is not consistent with Enel’s results, where *quality* was almost identical for all methods (see Figure 11).

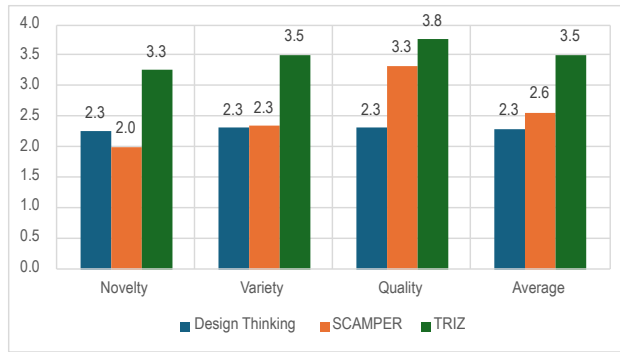


Figure 11. Performance of the methods for the innovation criterion (BAYER Challenge)

4.2.2. Criterion 2. Business Development

TRIZ performs better in all variables, while SC and DT exchange places between variables and challenges (see Figure 12 and 13). The methods global results were slightly better in Enel, which was also observed in criterion one.

In Enel, TRIZ performs better in all variables, especially in *Innovation potential*; SCAMPER shows the weakest performance, matching DT only in *customer focus*. The *Presentation* of the solution-idea and business model were especially low, independent of the method. In general, teams that worked with DT presented the problem in the form of a question, the teams that worked with TRIZ in the form of a contradiction, and the teams that worked with SCAMPER described the problem in a basic paragraph.

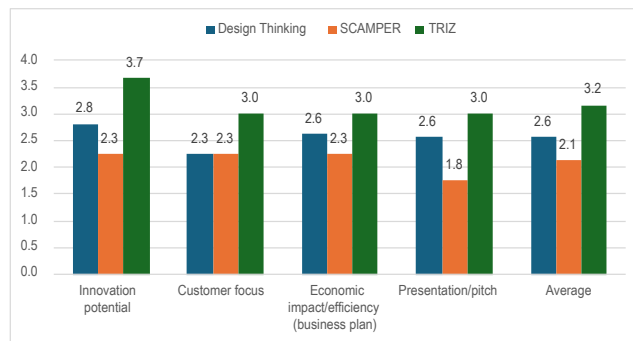


Figure 12. Performance of the methods for the business development criterion (ENEL)

In Bayer, TRIZ performs better in every variable, being approached only by DT in *Presentation*, while DT and SCAMPER exchange the second place (two variables each). The difference in results between TRIZ and DT in *Customer focus* and *Economic impact* is especially interesting, since DT claims to have a customer-business orientation, which is reflected in the results.

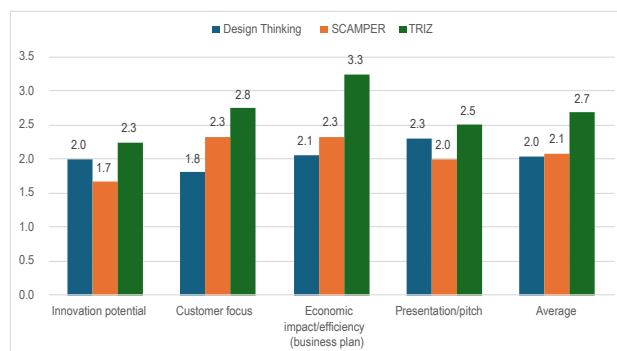


Figure 13. Performance of the methods for the business development criterion (Bayer)

4.2.3. Criterion 3. Teamwork

TRIZ performs better in both challenges, especially in *Problem definition*, while DT and SC have similar performances (see Figure 14 and 15). However, TRIZ was surpassed by SCAMPER in Bayer's, *Teamwork*. In Enel, TRIZ performs better in every variable, being *User characterization*, the only variable where SCAMPER approaches IT, and *teamwork* the only variable where DT does it. In general, DT and SC have similar results, The *Definition of the problem* difference is especially significant.

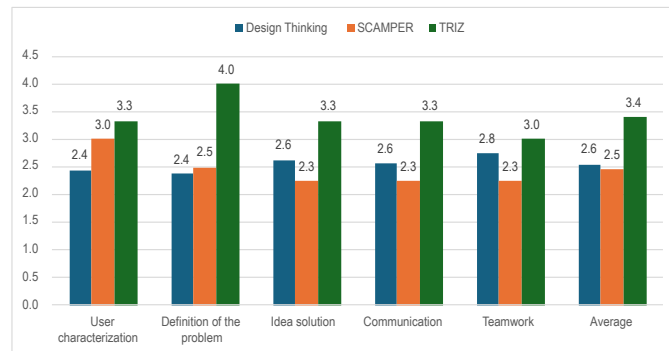


Figure 14. Performance of the methods for the teamwork criterion (ENEL Challenge)

In Bayer, TRIZ average performance was the best one, however, this is the only criterion where it was surpassed by other method, SCAMPER, specifically in *Teamwork*; this result is not consistent with Enel results, where SCAMPER was the method with lower results, revealing a potential specific influence of the challenge nature in method's performance. In *Communication*, all methods performed similarly, and *definition* showed the biggest difference, supporting the potential benefits of defining problems as contradictions.

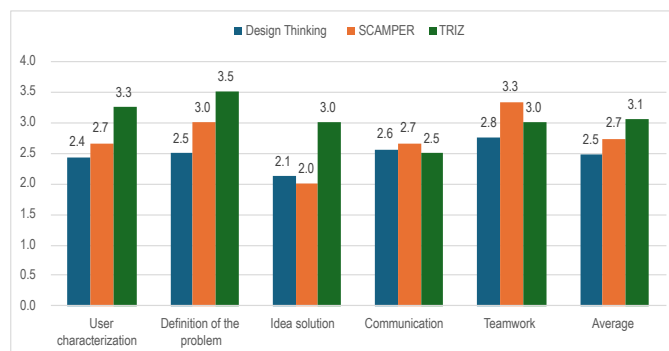


Figure 15. Performance of the methods for the teamwork criterion (Bayer Challenge)

5. Discussion

The objective of this study is to explore the effect of design methods when developing value-added solutions that can be transferred to the market. Two open innovation challenges were addressed using 3 design methods, and the participants' proposals were quantified using 3 main criteria.

5.1. Between Challenges

The results show that, despite using similar methods and having participants with comparable backgrounds, there were significant differences between challenges, suggesting that their nature (e.g., focus and scope) had a relevant impact on participant performance. Globally, Enel with its environmental focus and local scope, showed better overall results (+6%) and lower dispersion (standard deviation = 0.15). The

biggest difference was observed in Criterion 2, business potential, with *innovation potential* as the most relevant variable (Bayer obtained a score of 2.0, and Enel 2.9).

A possible explanation is that the more speculative nature of the Bayer challenge likely affected the feasibility of the proposals. Speculating on topics such as digital medicine and cybersecurity requires basic technical knowledge that participants likely lack access to; that is, the students' background becomes more relevant. In contrast, the Enel challenge dealt with variables that participants receive information frequently, like urban development, digitalisation, or circular economy.

When analysing each criterion, it stands out that in criterion 3 the difference is almost non-existent; this supports the idea that the nature of the challenges does not significantly influence how each team works; all teams worked collectively, which seems to have made this criterion almost neutral in the overall results.

5.2. Among Methods

5.2.1. Criteria, Global

TRIZ obtained better results in all criteria in both challenges, almost in all variables. Considering that the maximum score was 96 points = 100% (12 variables, 4 points each, 2 challenges) TRIZ reached 80%, while DT and SCAMPER reached 61% each (see Figure 16).

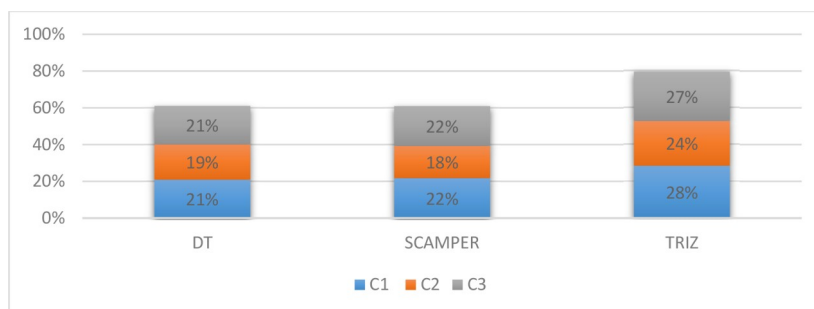


Figure 16. Global performance of methods relative to the ideal (96pts=100%)

Previous studies have shown relatively better performance of structured methods in general when compared to more intuitive ones (like Brainstorming); since this happened in evaluations with *Academic* related criteria, it was expected that the specific context of each challenge to play a relevant role; for example, TRIZ could have an advantage at Enel due to its technical and systematic requirements, and this advantage should disappear in a more open or globally oriented challenge, such as Bayer, considering that having lower restrictions could allow more diverse results across methods. However, TRIZ performance was better in both challenges across all evaluation criteria, independently of the participants. The “transversal-total-dominance 16% absolute advantage” was unexpected; for example, it would have been natural for DT to perform better in criterion 3, given its cooperative nature. However, it was outperformed by TRIZ in both challenges and by SC in Bayer. Previous research suggests that TRIZ’s structured approach, based on principles and the resolution of contradictions may yield academic benefits, that also manifested in the other criteria of the challenges. Probably the exploring of unnatural search spaces gives an advantage above SC more generic suggestions, or DT focus on conceptual development.

Another unexpected result was that, overall, DT and SC had similar results, with relevant differences in specific variables. It was expected that DT structure and their emphasis in customer focus could deliver better results when market objectives are considered, which happened in C2, business-Bayer in ENEL challenge (around 20%), but this advantage was absorbed by the other criteria in both challenges. ENEL “Smart cities” challenge involved day to day circumstances, where the “social emphatic nature” of DT should have given an advantage, but it was only 5% (TRIZ was 23% ahead). However, their dispersion showed important differences: DT standard deviation was 0.29, SC: 0.45, and TR: 0.42. It is possible that DT implementation, which involves more steps and the participation of mentors to guide the creative

process, created a more stable process that had an impact on producing more consistent results. This guidance could also be one of the causes of the low performance of DT, perhaps limiting participants' creativity due to mentors' observations or involuntary restrictions.

5.2.2. Criteria, Separated

When considering each criterion independently, the conclusions are similar, due to this “parallel” behavior among methods (see Figure 17). The only variable that breaks the similarity of results between SC and DT is “Presentation/pitch,” from ENEL's criterion 2 (SC “losses” by an observable margin), which allows us to speculate that the way the proposal was defined could have influence the result. TR and DT require specific definitions (contradiction and question, respectively), which can help to convey a clearer proposal when compared to an open explanation, as in SC.

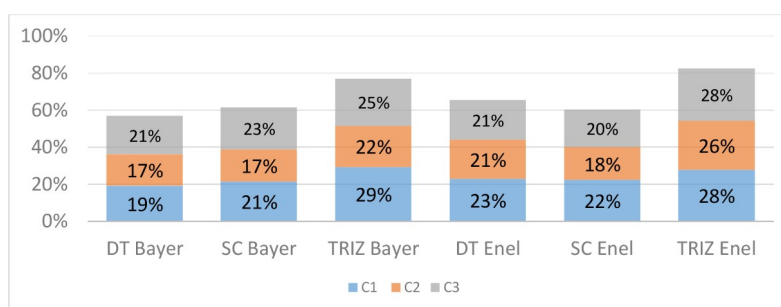


Figure 17. Performance of methods by challenge relative to the ideal (96pts=100%)

5.3. Potential Interferences/External Variables

Considering how the experiment was carried out, relevant differences could be caused by several variables, like the diversity of participants or their previous knowledge (see section 3). However, no effect was observed, which is consistent with previous studies where previous knowledge did not show an observable impact in inventive-nature challenges.

Another potentially relevant influence is the evaluators. Since the scores are assigned by experts, a good score is related to how much the participants proposals are aligned with the evaluator's opinion; however, it is unlikely that all evaluators are in synchrony with TRIZ principles, having a relevant influence on the results observed.

The challenge orientation towards the future could also interfere with the methods' effect, favouring intuitive approaches over technical ones, but that simply did not happen.

Finally, all methods have lower scores in criterion 2. Probably, the lack of cross-sectional experience of the participants developing commercial initiatives had a non-anticipated effect, which is consistent with the observations of the nature of the challenges.

6. Conclusions

The study examines the performance of different innovation methodologies—namely TRIZ, DT, and SCAMPER—in two distinct challenges: Bayer's data-driven farming and Enel's environmental one, in order to measure the effectiveness of problem-solving methods in the development of value-added solutions for open innovation challenges. The challenges are designed to address future societal issues with varying scopes and focuses. Enel's is localised and environmentally oriented, while Bayer's is global and speculative, focusing on digital therapeutics and cybersecurity.

The background of participants (including engineering, law, health sciences, design, and journalism) did not show significant effects on performance, indicating that the methodologies themselves, rather than participant expertise, are the primary drivers of performance.

Due to the exploratory nature of the study, the expectations were better global results for TRIZ, and better results for DT in coming up with new and diverse ideas, especially in Bayer scenario. However, TRIZ emerges as the most efficient methodology, consistently outperforming DT and SC across all criteria and context, showing that its inherent constraints and structure can be advantageous for idea generation, especially in ambiguous situations when technology transfer is intended.

The results suggest that, while DT and SCAMPER have specific advantages that should be potentiated, TRIZ's ability to explore non-familiar spaces and materialize creative ideas into market-valuable solutions gives it a distinct advantage in both localized and global contexts.

7. Future Work

While numerous studies demonstrate TRIZ's effectiveness in design and problem-solving, its adoption in organisations, education, and consulting remains limited when compared to DT and other methods and techniques. Future research should investigate the underlying reasons for this disparity, as a deeper understanding could inform the development of hybrid methodologies that combine the analytical strengths of TRIZ with the accessibility and popularity of DT. Such hybrid approaches may facilitate easier implementation in practice and potentially lead to superior design outcomes.

Additionally, the collaborative nature of DT did not yield a positive impact in the present study. Future studies could address this limitation by including individual (single-person) teams alongside collaborative ones. This comparison may provide further insights into user experiences, reveal preferences or affinities between specific methods and user profiles, and clarify the conditions under which collaboration is most beneficial.

Finally, future work could explore the integration of supporting tools such as Quality Function Deployment (QFD); incorporating QFD may help to further strengthen customer-focused design processes and improve the systematic assessment of economic impact, thereby enhancing the practical relevance and managerial value of design methodologies.

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Authors' contributions

Felipe Torres-Benoni: design, conceptualization, data processing, formal analysis, research, writing. Interpretations of results.

Roberto Durán-Novoa: data processing, formal analysis, research. Interpretations of results.

Data availability

Data included in the article itself or supplementary material.

Use of Artificial Intelligence

The authors declare that the content of the article has not been developed using Artificial Intelligence.

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