

DESIGN THINKING AND DESIGN OF EXPERIMENTS: THE FUSION OF THE SCHOOL OF DESIGN AND INDUSTRIAL ENGINEERING TO CREATE LEARNING EXPERIENCES IN THE TEC21 EDUCATIONAL MODEL

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ABSTRACT

Two characteristics of the Tec21 Educational Model at Tecnológico de Monterrey are learning-based-on-challenges (LBC) and the attempt to provide memorable experiences during university education. These challenges and experiences are being created through activities to develop problem-solving competencies in the students. These activities where they apply their classroom learning are designed to be attractive and challenging for the students. The Industrial Engineering and Design departments of Tecnológico de Monterrey have merged the design of experiments and design thinking to create a methodology that allows students to design successful academic activities and provides added value in education.

During the last 12 years, students at Tecnológico de Monterrey have experienced various activities both in *Semana i* and *Semestre i* (new class periods created under the Tec21 Educational Model). The learning activities contained challenges to resolve during the school periods, which evidence significant learning, as reported in the end-of-semester evaluations. By proposing academic activities based on a multilevel factorial model, a statistical model has been generated to find the best combination of the component factors and levels to give us a probability of success greater than 90% when implementing the activities. Following the design-thinking methodology allows the institution to immerse with the students, be empathetic, and clearly define our expectations of them and, consequently, have a robust activity design. Various design factors are built into the activities to make them attractive and challenging for the students and enable them to apply their classroom learning.

Keywords: Design thinking, design of experiments, competencies, educational innovation, higher education

1 INTRODUCTION

According to Henriksen [1], the problems faced by educators in professional practice are complex, varied and difficult to tackle. These problems include teaching and learning issues, social or community problems, trouble in the classroom environment, and many others. The problems are multifaceted, interdisciplinary, derived from human activity, and rarely resolved through simple or linear approaches [2]. Moreover, confinement due to the COVID-19 virus has added additional problematic layers to resolve.

In 2019 Tecnológico de Monterrey started the full implementation of its new educational model known as Tec21 which is based on LBC and memorable experiences such as *Semana i*, *Semana Tec*, *Semestre i* and *Semestre Tec*. For these activities to be truly memorable, they needed to be designed to be attractive to students, obey academic rigor, and lead students to develop real-world skills. The proposed methodology for the activities' design is based mainly on combining two design tools: Design Thinking (DT) and Design of Experiments (DOE), and other creative phase techniques.

2 DEVELOPMENT

The design of activities within Tec21 has unique characteristics that differentiate Tecnológico de Monterrey from other educational institutions. The differentiation includes challenging, engaging curricular activities to develop real-world skills and leave a deep educational footprint. Since 2012, Tecnológico de Monterrey has been designing an educational teaching model based on challenges that develop assessable skills in students for 21st century. The challenge to be resolved must engage the students, motivate them to work collaboratively, boost knowledge acquisition, and develop the necessary skills in the best possible way.

Henriksen [1] notes that while creativity is considered a core 21st century thinking skill, many people are hesitant to identify themselves as "creative," or they are uncomfortable with intellectual risk-taking and openness. In her article *Why DT works*, Liedtka [3] describes a seven-year study looking closely at 50 projects from various sectors, including business, healthcare, and social services. She found that another social technology, design thinking, can innovate the way we do things by unleashing people's creative energies, thereby improving several processes radically. Therefore, design thinking as a tool in current education can promote real-world problem-solving, enabling students to develop competencies to address economic and societal issues.

The proposal consists of using design thinking and the design and analysis of experiments to confront the posed challenge and propose the best possible solution. Creative and statistical thinking work together to achieve optimally creative solutions and, consequently, the desired skills. Wattanasupachoke [4] suggests that the most innovative organizations use design thinking. Carlgren et al. [5] identified five characteristics of the design thinking framework: attention, understanding the problem, prototyping, iteration, and diversity. These characteristics are summarized in Table 1.

Table 1. Design thinking framework, Carlgren et al. [5]

Characteristics	Alternative labels
User focus (attention)	<ul style="list-style-type: none"> ● User orientation ● Customer focus ● Human-centred
Problem-framing (understanding the problem)	<ul style="list-style-type: none"> ● Unconstrained view of the problem ● Question the problem ● Problem exploration ● Problem focus
Prototyping	<ul style="list-style-type: none"> ● Visualization ● Making it tangible
Iteration	<ul style="list-style-type: none"> ● Iteration and testing ● Action-oriented ● Experimentation
Diversity	<ul style="list-style-type: none"> ● Collaboration ● Systemic perspective

Meinel, Eismann, Baccarella, Fixson, and Voigt [6] found that teams applying design thinking develop better product concepts than teams that apply quality function deployment in terms of feasibility, relevance and specificity, but not a novelty. Researchers claim that the design thinking approach to innovation has several positive outcomes. It helps develop superior solutions, reduce the risk of failure, achieve employee buy-in, and increase the firm's innovativeness and dynamic capabilities for innovation [7,8,9,10]. Design thinking is a methodology that had its origins at Stanford University in California. It focuses on the user and their needs. Although DT is commonly used in product design, it can be applied to the design of academic activities, challenges and experiments design. This is shown in Figure 1.

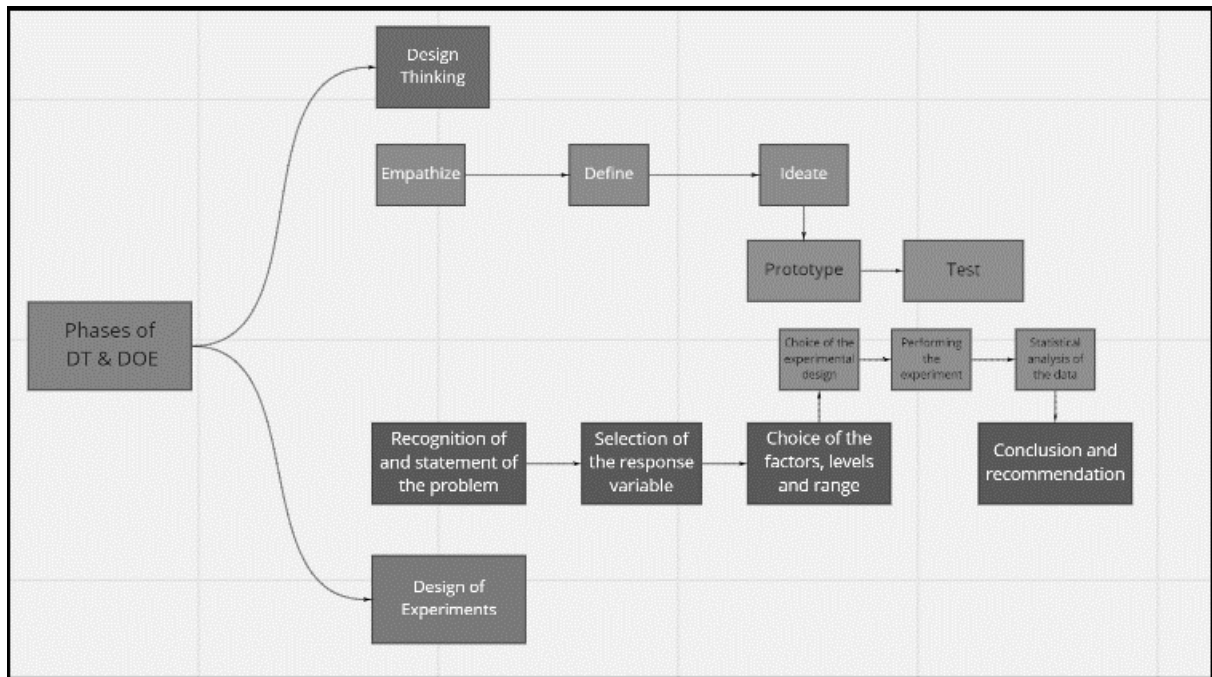


Figure 1. Phases of Design Thinking and Design of Experiments Self-elaborated.

Empathize means putting yourself in the user's shoes, having a deep sensitivity to see from the student's eyes, feeling their needs. In this phase, mind maps and brainstorming are used, and the design of surveys aimed at gathering the needs and proposals. Hüseyin [11] proposes a methodology to select the ideal questionnaire for information collection. In this case, it would be the interview with key clients in which the interviewer collects data from people who have unique insights that would otherwise not be available to the researcher.

In the Ideate part, methodologies are used to define the activity, the challenge, or the problem. The most common are the creative phase technique (brainstorming, mental maps, etc.), engineering thinking (mathematization of ideas based on set algebra), and Kepner's and Tregoe's criteria for identifying and defining problems [12]. In this stage, the hypothesis is defined by describing the users' needs (e.g., the students), the competencies to be covered, the academic content, and the current environment's demands. In the Ideate phase, solutions are proposed based on a correct definition of the problem. The use of thought engineering (see Figure 2) is vital. Set algebra is used to isolate the determining factors.

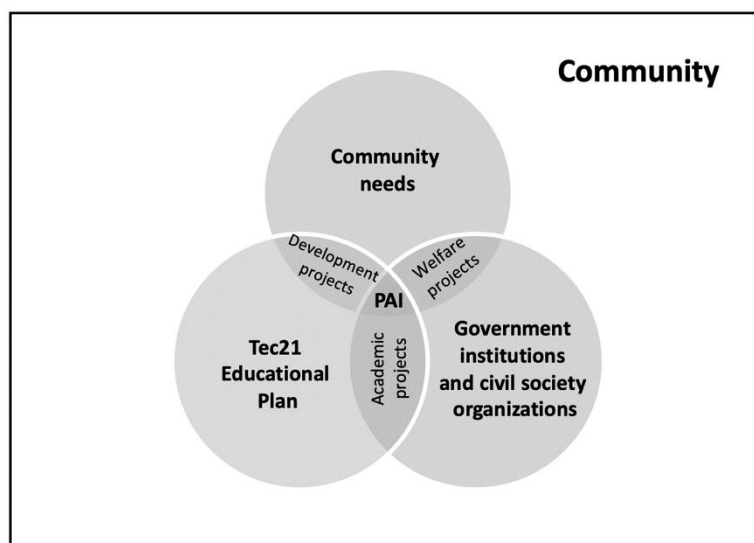


Figure 2. Example of thought engineering. Own source

During the Ideate phase, thought engineering was used to determine the factors that give a solution to the problem and a test is used to determine if the factors are correct. This stage is commonly done by trial and error, which prolongs the time it takes to propose a solution. To solve this, the use of a factorial experiment design of two or more factors and limiting it to 2^K designs where the K is the number of factors, and 2 represents the levels (categorized as high or low.) was proposed.

The activity design [13], such as the beta version or the prototype, is made starting from the brainstorming structure. The academic activity begins to be written following the steps that were previously defined. When a teacher talks to the students about problem-solving, he or she asks them to generate a prototype that conceptualizes the idea. For the *Semana i* and *Semestre i* projects, teachers point out that in the prototyping stage, three phases are proposed: a) the conceptual prototype, where the physical form of the idea is given; b) the functional prototype, where the product has the materials and operates according to specifications, and c) the sellable prototype, in which a product is created with proven materials, functioning according to specifications and meeting all quality and safety requirements.

A similar analogy was used by the teachers to design activities and challenges that meet all the academic requirements and guidelines established by the Vice-rectory. In this prototyping stage, the group of teachers lives the challenge; that is, they carry out the activities of the training unit's curricular project. By doing this, they can adjust the times to carry out each stage of the challenge; the materials' requirements are also established. Adjustments to the instructions and necessary corrections are usually made when testing a prototype.

At the trying phase, the proposed solution's desirability and feasibility are checked, so the experiment's design must be present. If a factorial design [14] is used, the factors can have more than two levels. This is very practical in the design of a new product. However, if the academic design of activities and challenges is analysed, then the use of a 2^K design is needed where the levels are low and high. One of the problems that faculty face is creating data to carry out the experiments, but these can be obtained based on simple simulations or the generation of random numbers based on a specific probability distribution. In the case of the activities and challenges, the normal or binomial distribution is used. In contrast, for a solution or product design, a triangular or Poisson distribution is used. The experimental design generates the value of the parameters of the factors or variables under study. By testing them, the development time can be reduced because the experimenter only has to readjust and not look for the appropriate values based on trial and error.

2.1 Theoretical framework

Design thinking has been used to educate in medical schools with two primary functions: the first, to develop a specific new product and the second, to develop in the students a problem-oriented way of thinking about the development of a new product [15]. Sanders J. and Goh P. [16] illustrate design thinking among second-year students to develop a new community service, highlighting as challenging the stakeholders' diverse perspectives and the introduction of extra activities to the medical students' curriculum. Design thinking has also benefited the business administration programme at the University of Amazonia, where students generate experiences corresponding to their reality as citizens. By applying DT principles, they can promote the learning of social thinking skills in other people [17].

Experiments are used to study the performance of processes and systems. The objectives of the experiment could include the following:

1. Determine which variables have the most significant influence on the Y response.
2. Determine which X adjustment has the most significant influence on the y variable, so it is almost always close to the desired nominal value.
3. Determine which X adjustment has the greatest influence, so the variability of y is reduced.
4. Determine which X adjustment has the most significant influence so that the effects of the uncontrollable variables z_1, z_2, \dots, z_q are minimal.

Usually, one of the experimenter's goals is to determine the influence these factors have on the system's output. The general approach to planning and experimenting is the experimentation strategy. The successful integration of good experimental design practice in engineering and science is crucial in future industrial competitiveness [18].

2.2 Implementation and innovation results

The methodology described above combines the Design of Experiments and Design Thinking to create activities for the *Semana i* and *Semestre i* of the Tec21 Educational Model. It is also a methodology for the solution of challenges. The projects derived from these activities increased the development of disciplinary and real-world competencies.

This methodology has been implemented in the last three editions of *Semana i* by teachers from the science, civil, mechanical, industrial and auxiliary departments. The results of the teachers' evaluations were measured using the students' comments and the numerical evaluation in the item "*Would you recommend this activity?*".

Impressive results were achieved both from teachers using the methodology to design *Semana i* and *Semestre i* activities and the students researching and developing projects for new products. Table 2 shows the results of the *Solidarity Route of the Sierra Gorda* activity. It displays the student evaluation results since 2016; the average evaluation for all years was 4.70 out of 5 possible points. Each year, the activity consisted of approximately 15 social development activities in surrounding communities.

In an average of 200 activities per *Semana i*, this activity was in 24.75th place of ranking in average.

Table 2. Results of the students' evaluation of the activity "*Solidarity Route of the Sierra Gorda.*"

Year	Enrolled Students	Proposed projects	Fulfilled projects	Efficiency	Student evaluation	Total activities	Ranking
2016	43	14	12	85.71%	4.9	116	8
2017	38	17	16	94.12%	4.8	114	21
2018	40	19	17	89.47%	4.38	128	51
2019	80	21	20	95.23%	4.7	117	19
Average	50.25	17.75	16.25	91.13%	4.70	118.75	24.75

This methodology has allowed students to carry out their projects, analyse the situation accurately, correctly define the problem, and solve it with creative, viable, and feasible solution proposals.

A comparative survey was carried out with 130 students who applied the methodology in *Semana i* activities and their final projects in various semestral courses. Even though 52.4% did not know the Design Thinking methodology and 57.1% considered the Design of Experiments to be a complex statistical technique, only 4.8% had problems implementing the methodology. This resulted in 100% of the projects in semestral courses being carried out and 94% of the projects in *Semana i*.

Besides, 86% of those surveyed considered this tool very useful to them in their professional and academic lives. Although 23% stated that they felt it difficult due to lack of prior knowledge, they could learn it by themselves and achieve an excellent use of the technique.

3 CONCLUSIONS

Academic innovations may take place in several scenarios. However, perhaps for those who carry out this research, the best thing is to propose methodologies that promote fun academic activities, solving real-world problems where students develop real-world skills for their professional and personal lives. They should feel empowered to propose viable and feasible solutions.

For teachers, the experience of applying the methodologies created fear, but not the type that paralyzed and led them to follow the established guidelines. Instead, this fear made them prepare the methodology even more, test it, and have the courage to allow students to find their own path to learning during the experiment. Although the results were very encouraging, we heed the comments that were not entirely positive. The methodology must be refined to fully develop the competencies defined by the Tec21 Educational Model for the students.

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REFERENCES

- [1] Henriksen D., Richardson C., and Merith R. S. Design thinking: A creative approach to educational problems of practice. *Thinking Skills and Creativity*. Volume 26, December 2017, Pages 140-15
- [2] Checkland P. J. *Oper Res Soc* (1985) 36: 757. <https://doi.org/10.1057/jors.1985.141>
- [3] Liedtka J. Why Design Thinking Works. *Innovation*. Harvard Business Review. From the September–October 2018 Issue.
- [4] Wattanasupachoke T. (2012). Design thinking, innovativeness and performance: An empirical examination. *International Journal of Management & Innovation*, 4(1), 1–14.
- [5] Carlgren L. (2013). Design thinking as an enabler of innovation: Exploring the concept and its relation to building innovation capabilities. Retrieved from <http://publications.lib.chalmers.se/records/fulltext/185362/185362.pdf%5Cnhttp://publications.lib.chalmers.se/publication/185362>.
- [6] Meinel M., Eismann T. T., Baccarella C. V., Fixson S. K., and Voigt K. I. (2020). Does applying design thinking result in better new product concepts than a traditional innovation approach? An experimental comparison study. *European Management Journal*, 38, 661–671. <https://doi.org/10.1016/j.emj.2020.02.002>
- [7] Brown T. and Katz B. (2011). Change by design. *Journal of Product Innovation Management*, 28, 381–383. <http://www.lavoisier.fr/livre/notice.asp?id=OKLWRXAKAR6OWL>
- [8] Liedtka J. (2014a). Innovative ways companies are using design thinking. *Strategy & Leadership*, 42(2), 40–45. <https://doi.org/10.1108/SL-01-2014-0004>
- [9] Liedtka J. (2018b). Why design thinking works. *Harvard Business Review*, 96(5), 72–79. Retrieved from <https://hbr.org/2018/09/why-designthinking-works>
- [10] Liedtka J. (2020). Putting technology in its place: Design thinking's social technology at work. *California Management Review*, 62(2), 53–83. <https://doi.org/10.1177/0008125619897391>
- [11] Atatürk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi 2009 13 (1): 201-216 Questionnaires and Interviews in Educational Research Hüseyin, Hasan.
- [12] Kepner Ch. and Tregoe B. (2013) *The New Rational Manager, An Updated Edition for a New World*. Kepner Tregoe Princeton Research Press.
- [13] Amiel T. and Reeves T. C. (2008). Design-based Research and Educational Technology: Rethinking Technology and The Research Agenda. *Educational Technology & Society*, 11(4), 29-40.
- [14] Dempster A. P. (1960) Henry Scheffé, The Analysis of Variance, *Technometrics*, 2:4, 517, DOI: 10.1080/00401706.1960.10489917
- [15] ElMaraghy W., ElMaraghy H., Tomiyama T. and Monostori L. Complexity in engineering design and manufacturing. *CIRP Annals-Manufacturing Technology*. 2012 Dec 31;61(2):793-814.
- [16] Sandars J. and Goh P.-S. (2020). Design Thinking in Medical Education: The Key Features and Practical Application. *Journal of Medical Education & Curricular Development*, 7, 1–5
- [17] Hernández-Gil C. and Alexis Núñez-López J. (2020). Design thinking aplicado al mejoramiento de las competencias ciudadanas en universitarios: voto popular. *Revista de Investigación Desarrollo e Innovación*, 11(1), 85–98. <https://doi.org/10.19053/20278306.v11.n1.2020.11685>
- [18] Montgomery D. (2011). *Diseño y análisis de experimentos*. México: Limusa Wiley.