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Enhancing Engineering Students' Problem-Solving Outcomes Through the Integration of Design Thinking and TRIZ: A Quasi-Experimental Study

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Abstract*– This study investigates the influence of embedding TRIZ (Theory of Inventive Problem Solving) within a Design Thinking framework on engineering students' problem-solving performance. The study employed a quasi-experimental design with 68 undergraduate engineering students who were assigned to two groups: a control group using Design Thinking (DT) and an experimental group using DT combined with TRIZ. The pedagogical design challenge that students tackled was the development of learning tools for neurodiverse children. Final solutions were appraised using a rubric that assessed creativity, originality, technical feasibility, and systematic coherence. Independent samples t-test analysis confirmed no significant differences in creativity and originality between groups; however, statistically significant improvements were observed in technical feasibility and systematic coherence in DT+TRIZ condition ($p < 0.05$). These results indicate that design thinking and TRIZ can enrich student solutions with high technical quality while not undermining creativity. These findings suggest that hybrid innovation frameworks can help engineering students balance creative ideation with technical rigor in complex problem-solving contexts.

Keywords—Design Thinking, TRIZ, Engineering Education, Creative Problem-Solving, Educational Innovation

I. Introduction

As our technological industries undergo rapid transformation, the need for engineers capable of creative problem-solving and systemic innovation has increased. Creative thinking and complex problem-solving skills, for instance, according to the World Economic Forum [1], are among the most vital competencies needed in the emerging workforce. As such, engineering education needs to incorporate frameworks that promote both divergent and convergent thinking. Design Thinking (DT), widely popularized by Tim Brown and further developed by IDEO, has emerged as a human-centered innovation framework [2]. DT also emphasizes empathy, iterative prototyping, and collaborative ideation. However, DT was found to be without structural rigor when responding to very complex technical contradictions [3], [4].

Genrich Altshuller's TRIZ (Theory of Inventive Problem Solving) is a structured methodology based on patterns of technological evolution and contradiction resolution. Research on the effect of TRIZ in structured creativity and technical robustness shows a noticeable increase [5], [6].

Although both methodologies have been widely studied independently, empirical research examining their combined pedagogical impact in engineering education remains limited. Integrating Design Thinking's human-centered exploration with the structured analytical tools of TRIZ could potentially balance creative ideation with technical feasibility.

Despite the extensive literature on Design Thinking and the growing body of work on TRIZ-based innovation, empirical studies examining the pedagogical impact of combining both methodologies remain scarce in engineering education. Most existing research focuses on conceptual discussions or isolated applications of each framework. Consequently, there is limited empirical evidence regarding how hybrid innovation methodologies influence students' problem-solving outcomes in real educational contexts.

Therefore, the present study investigates the following research question:

How does the integration of Design Thinking and TRIZ influence the creativity, originality, technical feasibility, and systematic coherence of engineering students' solutions compared to Design Thinking alone?

By empirically examining this question through a quasi-experimental study, this research seeks to contribute evidence on how hybrid innovation methodologies may strengthen problem-solving outcomes in engineering education.

II. Literature Review

A. Design Thinking (DT) as Pedagogical Paradigm in Engineering

In the context of contemporary engineering education, Design Thinking has evolved from a design practice into a widely adopted pedagogical framework [7]. The approach is particularly useful for addressing "wicked problems," which are characterized by high levels of uncertainty, incomplete information, and complex stakeholder interactions [8].

Design Thinking places human needs at the center of the innovation process and follows an iterative cycle that includes empathy, problem definition, ideation, prototyping, and testing [9]. Beyond its procedural stages, DT encourages abductive reasoning and experimentation, enabling engineers to explore possibilities that extend beyond traditional analytical approaches [10][11]. Several studies highlight that Design Thinking improves problem framing, collaboration, and iterative learning in complex problem contexts [12].

From a cognitive perspective, Design Thinking is strongly associated with divergent thinking, a concept originally introduced by Guilford [13] and later expanded within creativity research [14]. Divergent thinking allows individuals to generate multiple alternative solutions and explore unconventional ideas during the early stages of problem solving.

Nevertheless, scholars have also highlighted potential limitations of Design Thinking. Dorst argues that DT interventions may produce superficial or incomplete solutions if they are not complemented with deeper analytical frameworks capable of addressing structural and technical complexities in engineering systems [15].

B. TRIZ: Systematic Innovation and Technical Optimization

While Design Thinking often relies on intuitive and exploratory processes, TRIZ (Teoriya Resheniya Izobretatelskikh Zadach) provides a structured and algorithmic approach to innovation. Developed through the systematic analysis of thousands of patents, TRIZ identifies recurring patterns in technological evolution and proposes generalized strategies for inventive problem solving [16]. TRIZ has been widely adopted in engineering education to enhance structured problem-solving and inventive thinking skills [17].

One of the central contributions of TRIZ is its focus on resolving contradictions. Engineering problems frequently involve trade-offs between desirable system characteristics, such as improving performance while minimizing cost or complexity. TRIZ provides tools such as the contradiction matrix and the forty inventive principles to help engineers overcome these conflicts while preserving system performance [5]. Recent educational implementations of simplified TRIZ frameworks have shown improvements in idea novelty and creative fluency among engineering students [18].

Another key concept in TRIZ is the Ideal Final Result (IFR), which encourages designers to envision optimal system functionality while minimizing resources and negative side effects. Research suggests that TRIZ can reduce reliance on trial-and-error experimentation and increase the predictability of the creative process [6].

Within engineering contexts, TRIZ has been shown to support technical optimization and structured innovation processes, making it particularly suitable for addressing complex technological challenges [19].

C. The intersection of Creativity and Technical Feasibility.

The relationship between creativity and technical feasibility is fundamental to successful engineering innovation. In professional engineering practice, creativity is generally defined as the generation of ideas that are both novel and useful [19].

This dual perspective is reflected in Amabile's componential theory of creativity, which proposes that innovation emerges from the interaction of domain-relevant skills, creativity-relevant cognitive processes, and intrinsic motivation [20].

Technical feasibility, on the other hand, refers to the extent to which a concept can be realistically implemented within existing engineering, physical, and economic constraints [21]. Recent research suggests that effective innovation processes require a balance between divergent and convergent cognitive mechanisms. Divergent thinking enables the exploration of multiple possibilities, while convergent thinking supports the evaluation and refinement of ideas into practical solutions [22].

For this reason, integrating the empathy-driven exploration of Design Thinking with the structured analytical tools of TRIZ may provide a complementary approach capable of enhancing both creativity and technical feasibility in engineering problem solving.

D. Synergy in the Methodologies and Formation of Professional Identity.

The integration of hybrid innovation methodologies in engineering education extends beyond the development of technical skills. It also contributes to the formation of students' professional identities as engineers capable of navigating complex socio-technical systems.

Exposure to both the human-centered divergence of Design Thinking and the analytical convergence of TRIZ may help students develop a balanced innovation mindset. Such an approach encourages sensitivity to user needs while maintaining the technical rigor required for engineering implementation.

Ultimately, this pedagogical synergy may help prevent innovation processes from stagnating at the ideation stage by ensuring that creative concepts are supported by systematic technical validation [17], [19].

Despite the growing body of research on Design Thinking and the increasing interest in TRIZ as a structured innovation methodology, empirical studies examining their combined pedagogical impact remain limited in engineering education. To address this gap, the present study proposes the conceptual framework illustrated in Figure 1, which integrates the exploratory strengths of Design Thinking with the analytical mechanisms of TRIZ. This framework guided the design of the quasi-experimental study described in the following section.

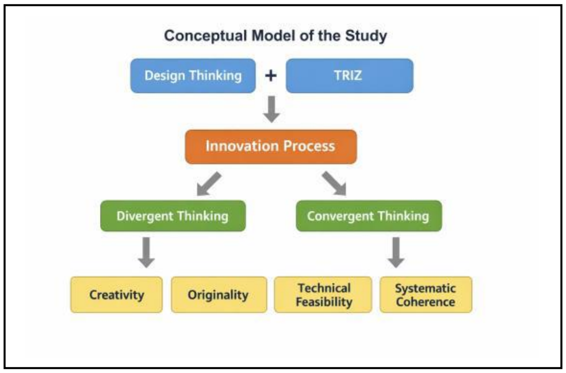

Figure 1. Conceptual model illustrating the integration of Design Thinking and TRIZ and its expected influence on engineering students' problem-solving outcomes.

III. METHODOLOGY

A. Research Design

This study employed a quasi-experimental research design to examine the impact of integrating TRIZ within a Design Thinking framework. A between-groups comparison was conducted between a control group using Design Thinking alone and an experimental group applying Design Thinking combined with TRIZ tools [18].

The independent variable was the innovation methodology used (DT vs. DT+TRIZ). The dependent variables consisted of four dimensions used to evaluate the quality of the proposed solutions: creativity, originality, technical feasibility, and systematic coherence.

Because students were assigned to intact classroom groups rather than randomly distributed, the study is classified as quasi-experimental. To enhance internal validity, both groups were taught by the same instructor and followed the same course schedule.

B. The Participants and Ethical Issues

The participants consisted of 68 undergraduate engineering students enrolled in the Innovation and Experimental Design course at a private Mexican university.

The sample was divided into:

- Control group (DT only): n = 34
- Experimental group (DT + TRIZ): n= 34

Participants ranged in age from 19 to 21 years and were in their third semester of engineering studies.

Convenience sampling was used based on course enrollment. All participants provided informed consent prior to the intervention, and the study was conducted following institutional ethical guidelines to ensure that participation did not negatively affect the educational experience of any student group.

Participation in the study was voluntary, and all student data were anonymized to ensure confidentiality.

C. Intervention Design

The intervention was conducted over a five-week period, totaling 15 contact hours. Both groups were tasked with solving an identical "pedagogical design challenge": developing an innovative tangible tool to enhance neuro-diverse children's learning processes.

1**. Phase 1:** Empathy and Definition (Weeks 1-2): Both groups performed user research, stakeholder mapping, and problem framing using standard DT tools (e.g., empathy maps, "How Might We" questions).

2. **Phase 2:** Ideation and Refinement (Weeks 3-4): This stage constituted the experimental manipulation.

- The Control Group utilized traditional brainstorming and morphological analysis.

- The Experimental Group was trained in TRIZ-specific tools. Specifically, they applied the Contradiction Matrix to identify technical trade-offs in their designs and utilized the 40 Inventive Principles to trigger non-obvious solutions. They also applied the Ideal Final Result (IFR) concept to refine their prototypes toward maximum functionality with minimum complexity.

3. **Phase 3:** Prototyping and Testing (Week 5): Both groups developed low-fidelity physical prototypes and conducted peer-testing sessions.

D. Data collection and instrumentation

To evaluate the quality of the proposed solutions, a structured rubric based on a five-point Likert scale was developed drawing from established frameworks in creativity and engineering design assessment.

The rubric evaluated four dimensions:

- *Creativity:* How novel and how imaginative something is.
- *Originality:* The uniqueness of the solution compared to current market benchmarks.
- *Technical Feasibility:* The feasibility of the solution in practical and engineering constraints [16].
- *Systematic Coherence:* The logical correspondence among the existing user needs and the proposed technical features.

The final proposals were masked (anonymized) and approved by three independent expert professors working in engineering design. Inter-rater reliability was rigorously tested, using the ICC [23] to evaluate scoring invariants. Furthermore, internal consistency of the instrument was confirmed with Cronbach's alpha assessed internal consistency [24].

While the rubric demonstrated strong reliability and internal consistency, further validation through exploratory and confirmatory factor analysis, as well as application across different educational contexts, would strengthen its robustness as an assessment instrument.

E. Statistical Analysis

Descriptive statistics (means and standard deviations) were calculated from all dimensions. The Shapiro-Wilk test was used to check the normality of the distribution prior to hypothesis testing and Levene's test to check the equality of variances. Independent samples t-tests were used to test if there were significant differences between the groups [25].

Finally, the extent of the experimental effects was evaluated with Cohen's d [26] (of which 0.2, 0.5, and 0.8 are small, medium and large effect sizes, respectively).

Effect sizes (Cohen's d) were calculated to complement p-values and provide a measure of the practical significance of the observed differences.

E. Rubric Validation

The evaluation rubric was reviewed by three experts in engineering design and educational innovation to ensure content validity. Inter-rater reliability was assessed using the Intraclass Correlation Coefficient (ICC), indicating strong agreement among raters (ICC > 0.80). Additionally, the internal consistency of the rubric was confirmed using Cronbach's alpha.

IV. Results

The comparative analysis revealed several differences between the outcomes produced by the two instructional approaches.

First, descriptive analysis of the ideation phase indicated that students in the Design Thinking (DT) group generated a larger number of initial concepts compared to the experimental group. On average, teams in the DT group produced 7.8 conceptual proposals, whereas teams in the DT+TRIZ group generated 5.3 proposals. This result suggests that the DT-only approach encouraged broader divergent ideation during the early stages of the design process.

However, differences became more apparent when evaluating the quality of the final solutions developed by each group.

TABLE I
Comparison Solution of Quality Between Methodologies

Evaluation Dimension	**DT Mean**	**DT_SD**	***DT-TRIZ_Mean***	***DT_TRIZ_SD***	***p value***	**Cohen´s *d***
Creativity	4.1	0.55	4.2	0.5	0.18	0.18
Originality	3.9	0.6	4.1	0.55	0.28	0.3
Feasibility	3.2	0.7	4.0	0.6	0.01	0.64
Systematic Coherence	3.3	0.65	3.95	0.58	0.02	0.59

Table I summarizes the comparative results across the four evaluation dimensions: creativity, originality, technical feasibility, and systematic coherence.

Both groups achieved relatively high scores in creativity, and no statistically significant differences were observed between the DT and DT+TRIZ conditions ($p > 0.05$). Similarly, although the DT+TRIZ group obtained slightly higher scores in originality, the difference between groups was not statistically significant.

In contrast, statistically significant differences were identified in technical feasibility and systematic coherence. Students in the DT+TRIZ condition achieved higher mean scores in both dimensions ($p < 0.05$), with moderate effect sizes according to Cohen's criteria.

Figure 2 presents the mean creativity scores obtained by student teams under both methodological conditions. As shown in the figure, creativity levels were similar across the two groups, indicating that the incorporation of TRIZ did not negatively affect the generation of creative ideas.

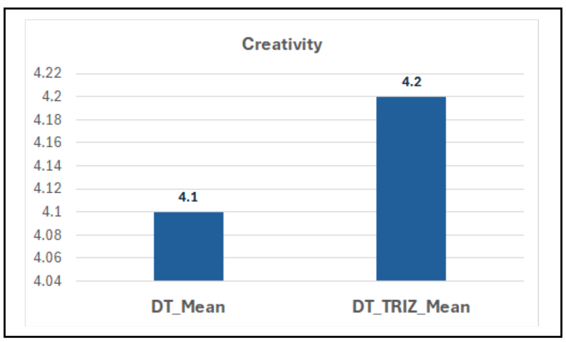

Fig. 2. Mean creativity scores obtained by student teams under the Design Thinking and integrated Design Thinking + TRIZ methodologies

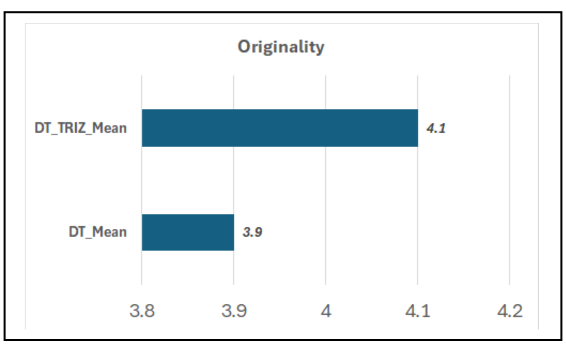

Fig. 3. Originality scores of student solutions

As shown in Fig. 3, the combined approach yielded marginally greater originality scores, indicating that the organization of inventive principles might promote the refinement of inventive ideas.

Fig. 4 shows the most pronounced difference between the two groups. Students using both the DT + TRIZ integrated method produced solutions with higher technical feasibility.

The results presented in Fig. 5 suggest that TRIZ contributes to a more ordered thinking process in solutions development.

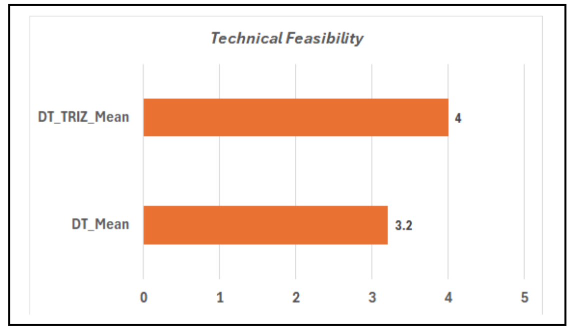

Fig. 4. Comparison of technical feasibility scores between the Design Thinking group and the integrated Design Thinking + TRIZ group.

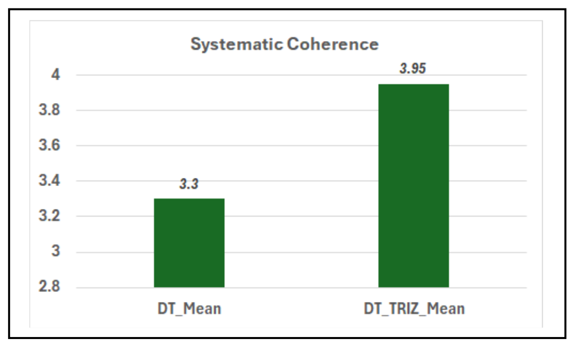

Fig. 5. Mean systematic coherence scores of student-generated solutions across both methodological approaches

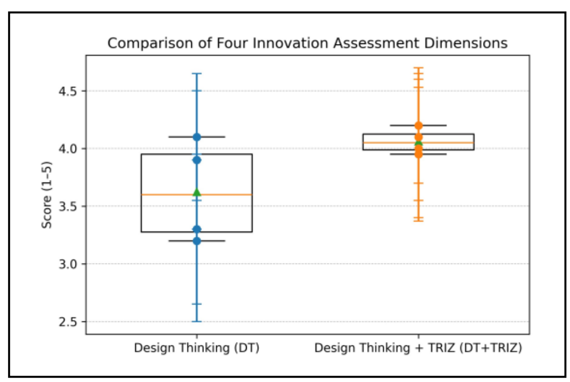

Fig. 6. Boxplot comparison of the four evaluated innovation dimensions for Design Thinking (DT) and DT combined with TRIZ.

Finally, Figure 6 presents a boxplot comparison of the distribution of scores across the four evaluation dimensions for both methodological conditions. The visualization shows that the DT+TRIZ group exhibits higher central tendency values in technical feasibility and systematic coherence, while maintaining similar levels of creativity and originality compared to the DT-only group.

Overall, these results indicate that while Design Thinking promotes strong ideation capabilities, the integration of TRIZ is associated with improved performance in dimensions related to technical implementation and structural organization of solutions.

V. Discussions and Limitations

The findings of this study provide empirical insights into the complementary roles of Design Thinking and TRIZ in engineering education.

First, the results indicate that Design Thinking alone effectively supports the divergent phase of innovation. Students in the DT group generated a larger number of initial ideas during the ideation phase, which aligns with previous research describing Design Thinking as a methodology that encourages exploration and creative ideation [2], [8].

However, the results also show that the integration of TRIZ significantly improved the technical feasibility and systematic coherence of the proposed solutions. Students who applied TRIZ tools developed concepts that were evaluated as more technically implementable and logically structured.

These findings support theoretical perspectives suggesting that effective innovation processes require the integration of both divergent and convergent cognitive mechanisms [17]. While Design Thinking facilitates creative exploration and user-centered problem framing, TRIZ introduces analytical tools that help engineers identify and resolve technical contradictions.

Another important finding is that the incorporation of TRIZ did not reduce creativity levels. Both groups achieved similar scores in the creativity dimension, suggesting that structured innovation methodologies do not necessarily constrain creative thinking. Instead, they may help transform creative ideas into solutions that are more technically robust.

From a pedagogical perspective, the results highlight the potential benefits of hybrid innovation methodologies in engineering education. By combining the human-centered orientation of Design Thinking with the systematic analytical tools of TRIZ, educators may help students develop a more balanced problem-solving approach that integrates creativity with technical rigor.

These findings contribute to the growing body of research emphasizing the importance of teaching innovation as a multi-stage cognitive process, where divergent ideation must eventually be complemented by structured evaluation and technical refinement.

Although this study provides relevant insights, several limitations should be acknowledged. First, the relatively small sample size (n = 68) and its restriction to a single institution may limit the generalizability of the findings to broader educational contexts. Additionally, the absence of full randomization (due to the use of intact classroom groups) introduces potential selection bias and limits the ability to establish strong causal inferences. While efforts were made to control instructional conditions, future studies should consider randomized controlled designs to strengthen internal validity. and should include larger and more diverse samples across multiple institutions and cultural contexts to enhance external validity.

Despite these limitations, this study contributes empirical evidence to a relatively underexplored area: the integration of structured and human-centered innovation methodologies in engineering education. The findings provide actionable insights for educators seeking to balance creativity with technical rigor.

VI. Conclusions

In this study, the influence of the integration of TRIZ methodology in a Design Thinking framework was investigated in an attempt to determine the impact on engineering students' problem-solving outcomes. With a quasi-experimental design, the performance of students using Design Thinking alone was compared with that of students using a combination of Design Thinking and TRIZ.

The results demonstrate that Design Thinking alone is capable of eliciting divergent ideation processes, namely students from the control group were generating a greater number of initial ideas. This finding reinforces the significance of Design Thinking as a design approach for pedagogical guidance in encouraging innovative inquiry and user-centered problem framing in engineering education. Furthermore, the findings indicate that the implementation of TRIZ is a significant help to technical feasibility and the systematic cohesion of student-developed solutions.

Students introduced to TRIZ tools were able to create solutions considered to be more technically feasible and more logically constructed given the user needs they had identified. Importantly, the introduction of TRIZ did not affect creativity levels negatively.

Creativity scores for both groups were similar, indicating that innovation methodologies may be a strength rather than a weakness in traditional structured approaches to creative thinking. It seems that rather than being in an inverse relationship with potential creative ideas, the incorporation of analytical tools seems to help to convert those creative ideas into technical solutions more robust and solid.

From an educational standpoint, these results imply the usefulness of hybrid innovation models in which human-centred designs are merged with more formal engineering problem-solving approaches. Such integration may support engineering students to build a more balanced innovation abilities mix of creative process and analysis and technical validation.

In general, this research provides empirical evidence of the effectiveness of incorporating Design Thinking and TRIZ instructional practices within engineering education. Therefore, an effective synthesis of the exploratory capabilities and conceptual concepts of Design Thinking with the analytical demands inherent in TRIZ would not only help educators meet diverse challenges but also equip students with creative skills to solve problems that apply to real-world situations.

Researchers can build on this effort to study future research and analyze the durability of hybrid innovation methodologies across engineering disciplines, over-scaled population segments, and different study environments. Moreover, future research might investigate how these emerging technologies (including AI-driven design tools) integrate with more structured innovation methods to improve students' creative and analytical competence.

Expanding the sample across institutions and disciplines would allow for a more comprehensive understanding of the scalability of hybrid innovation methodologies.

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