TRIZ-Driven Project-Based Learning to Foster Creative Problem-Solving in Engineering Education

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ABSTRACT

In engineering education, fostering students' ability to create innovative, real-world solutions is vital, especially at the diploma level where Final Year Projects (FYPs) serve as capstone experiences. This paper examines the integration of the Theory of Inventive Problem Solving (TRIZ) into a diploma-level FYP to strengthen technical creativity and structured learning outcomes. Although TRIZ is well established in industry and higher education, its use in technical and vocational education and training (TVET) remains limited. This study demonstrates how TRIZ can be systematically applied in diploma-level FYPs through the "Pick and Pay" case study, a smart shopping cart system developed by engineering students at Universiti Teknologi MARA. Additionally, it evaluates TRIZ's pedagogical impact on student learning, focusing on systematic creativity, engineering judgment, teamwork, and alignment with Program Outcomes (POs) required by the Engineering Technology Accreditation Council (ETAC). Guided by six TRIZ inventive principles: Equipotentiality, Another Dimension, Mechanics Substitution, Intermediary, Colour Changes, and Copying, the students developed a functional prototype featuring RFID-based scanning, loyalty card integration, and real-time billing automation. Reflections showed improved confidence, problem-solving, and collaborative design. The findings highlight TRIZ's dual value: enhancing prototype innovation and serving as an effective pedagogical tool in diploma-level engineering education.

Keywords
TRIZ in Education; Engineering Pedagogy; Creative Thinking Skills; Project Based Learning; ETAC Program Outcomes

Introduction

The demand for adaptive, creative, and innovative problem-solving skills in engineering education (Munir, 2022) has never been more urgent considering technological advancement and increasingly complex societal needs (Rahim & Iqbal, 2020). To prepare students for these real-world challenges, it is critical to cultivate both technical competencies and inventive thinking skills (Ferreira, 2024), especially at the diploma level, where Final Year Projects (FYPs) serve as students' first exposure to full-cycle engineering design. The Theory of Inventive Problem Solving (TRIZ), developed by Genrich Altshuller, offers a systematic and structured approach to innovation. By resolving contradictions and drawing from patterns of invention, TRIZ empowers students to generate creative yet practical engineering solutions (Rodriquez et al., 2016). While TRIZ has seen wide application in industry (Makulova et al., 2023; Yang & Tsai, 2021), and postgraduate research (Ghane et al., 2024), its implementation in technical and vocational education and training (TVET), particularly for diploma level engineering FYPs, remains limited.

In particular, few studies have explored how TRIZ supports real-world prototyping and aligns with Program Outcomes (POs) required by the Engineering Technology Accreditation Council (ETAC). This paper addresses this gap by presenting the Pick and Pay project, a low-cost, interactive smart cart system developed by diploma students at Universiti Teknologi MARA. The system integrates RFID-based scanning and loyalty-card payment features and serves as a case study of how TRIZ can be embedded into the FYP process to support both technical innovation and structured educational outcomes.

The adoption of TRIZ into Pick and Pay was guided by principles such as Equipotentiality, Another Dimension, Mechanics Substitution, Intermediary, Colour Changes, and Copying. These principles not only informed the technical design but also cultivated higher, order thinking, creative reasoning, and systematic problem solving among the students. Specifically, this paper pursues two objectives. First, it demonstrates how TRIZ can be systematically applied through the development of the "Pick and Pay" smart shopping cart system developed as a diploma-level FYP. Second, it evaluates the pedagogical impact of TRIZ on student learning, focusing on creativity, engineering judgment, teamwork, and alignment with key Program Outcomes (POs) outlined by ETAC. By clearly articulating both the technical and educational contributions, this study aims to provide evidence for the broader adoption of TRIZ as a structured innovation framework in diploma-level engineering curricula.

The remainder of this paper reviews relevant literature on TRIZ in engineering education, presents the Pick and Pay case study, and evaluates its pedagogical impact on student learning and professional skills.

Literature Review

The need to cultivate innovative problem (Zhang et al., 2021), solving skills among engineering students has gained renewed urgency as the profession faces complex (Wu et al., 2023), multidimensional challenges. As engineering education continues to evolve to meet the challenges of the Fourth Industrial Revolution, the development of inventive problem-solving capabilities among students has become a pedagogical imperative (Abd Nasir et al., 2023). Diploma level engineering programs emphasize hands-on learning and real-world application (Tze Kiong et al.,2019), making them an ideal environment for innovation focused methodologies like TRIZ. Traditionally, FYPs in diploma education are structured around technical implementation and documentation. However, without structured frameworks for creativity, students often struggle to move beyond conventional solutions (Mejia-Villa et al., 2023). TRIZ addresses this gap by systematizing the innovation process (Marinah et al., 2018) helping learners resolve contradictions using tools like the 40 Inventive Principles and the Contradiction Matrix (TRIZ, 2003).

Several studies affirm TRIZ's educational benefits. Chang et al., (2016) found that TRIZ training significantly enhances student creativity, while Cano-Moreno et al., (2022) reported improved ideation in diploma capstone projects. Brown and Bauer (2021) also noted that students using TRIZ showed greater confidence in problem abstraction and design decision-making. The Pick and Pay project reflect this pedagogical value. Guided by TRIZ principles such as Equipotentiality and Mechanics Substitution, students developed a functional prototype under typical resource constraints (Hasanzadeh & Eslampanah, 2019). Sheng (2023) further supports TRIZ's relevance to TVET contexts, showing that learners trained in TRIZ outperform peers in producing technically valid design alternatives. Importantly, TRIZ aligns with Malaysia's Outcome-Based Education (OBE) framework (Rahim & Iqbal, 2022) which emphasizes the attainment of Program Outcomes (POs) such as solution design, tool application, and project management. Mohamed et al., (2019) observed that TRIZ scaffolds reflection and improves documentation quality essential components in diploma-level FYP evaluation. Moreover, TRIZ integrates effectively with prototyping platforms such as Arduino, RFID, and IoT systems (Chrząszcz, 2025; Santoso et al., 2024), making it highly relevant for current engineering curricula.

Recent research has provided strong evidence of TRIZ's pedagogical value when integrated into engineering curricula and project-based learning. For instance, Hmina et al. demonstrated how TRIZ tools, when combined with an energy-analysis framework, enhanced engineering students' ability to solve complex design challenges, as shown in the development of an innovative wastewater filtration system. The study reported both qualitative and quantitative improvements in students' conceptual understanding and inventive problem-solving (Hmina et al., 2024). Complementing this, Panikar et al. explored a TRIZ-Integrated Design Thinking approach with 200 engineering undergraduates in Oman, using structural equation modelling to show significant positive relationships between TRIZ-driven pedagogy, innovation capability, and prototyping confidence (Panikar et al., 2025). Meanwhile, Coello et al. highlighted the synergy of TRIZ with STEM and Industry 4.0 skills in an applied physics course in Ecuador, showing that TRIZ-supported didactic strategies measurably improved students' professional competencies, teamwork, and problem-solving abilities (Coello et al., 2024). These recent studies from Morocco, Oman, and Ecuador demonstrate that integrating TRIZ with design thinking, STEM, and Industry 4.0 frameworks significantly enhances engineering students' innovation capability, problem-solving skills, and professional competencies.

Despite its promise, TRIZ adoption in diploma education specifically remains limited due to perceived complexity and a lack of trained facilitators. However, recent initiatives such as simplified TRIZ toolkits, guided worksheets, and project-based templates have increased its accessibility. This paper contributes to a growing body of research advocating TRIZ as a core instructional strategy for enhancing both the innovation quality and educational outcomes of diploma-level engineering project.

Methodology

This study employed a qualitative case study design framed within a structured project-based learning approach underpinned by the TRIZ methodology. The Pick and Pay project was undertaken by two diploma-level engineering students from Universiti Teknologi MARA as part of their FYP. A single-case, small-sample design was selected because the primary aim was to demonstrate the integration of TRIZ into an FYP and to explore its pedagogical impact on student learning.

The research design followed three sequential phases: Problem Identification, TRIZ-Driven Design, and Prototype Implementation, as illustrated in Figure 1. TRIZ was embedded throughout the students' design activities using structured steps of contradiction analysis, inventive principle selection, and prototype development. Six TRIZ principles: Equipotentiality, Another Dimension, Mechanics Substitution, Intermediary, Colour Changes, and Copying, guided specific design decisions, with each feature mapped to corresponding TRIZ principles and evaluated against the Engineering Technology Accreditation Council (ETAC) Program Outcomes (POs).

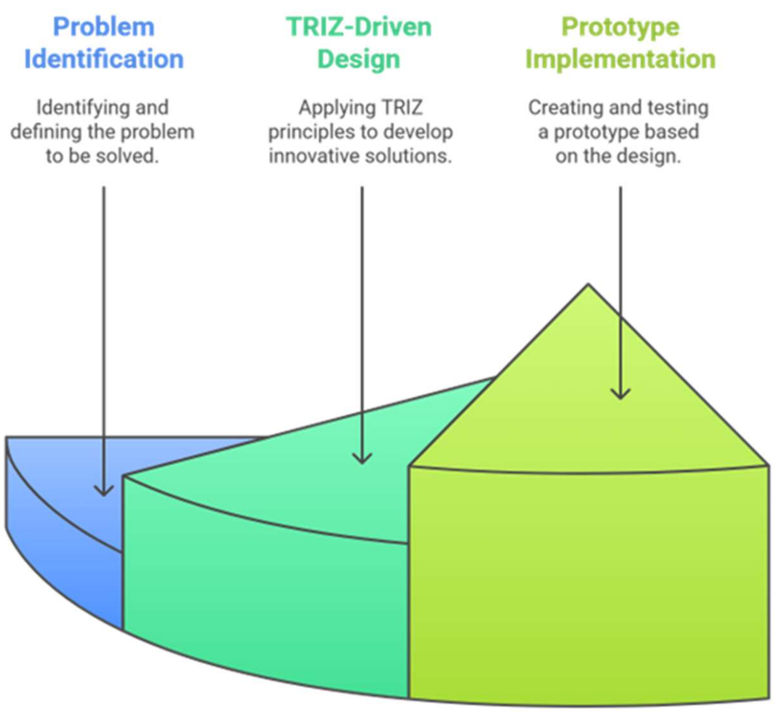

Figure 1. TRIZ Methodology Implementation

To evaluate the pedagogical impact, data was collected through semi-structured interviews conducted at the end of the project and supplemented with student reflective journals maintained during the design process. The reflections provided evidence of TRIZ's influence on creativity, engineering judgment, teamwork, and systematic problem-solving. Interviews were audio-recorded, transcribed, and coded. A thematic analysis approach was applied to identify recurring patterns, supported by direct student quotations.

Although limited to a single project and two participants, this study ensured rigor through data triangulation, comparing interview responses, reflective journals, and TRIZ design logs. The richness of the qualitative evidence provided meaningful insights into how TRIZ supports both inventive design and learning outcomes.

TRIZ-Based Problem Formulation and Contradiction Analysis

The methodology began with identifying practical and operational challenges within conventional retail checkout systems. Two primary issues emerged: (1) long wait times for customers with few items due to shared queues, and (2) reduced staffing efforts undermined by continued reliance on manual checkout processes, these formed by the core problem statement. To approach this systematically using TRIZ, the challenge was reframed as an engineering contradiction:

If *the checkout system is made faster and more user-friendly,*
Then *customer satisfaction and productivity improve,*
But *the solution becomes more complex and costly to implement.*

This contradiction, when applied to the TRIZ Contradiction Matrix (Improving parameter; Row 33: Ease of Operation vs. Worsening parameter; Column 36: Device Complexity), yielded the following recommended inventive principles: #32, #26, #12, and #17. A second matrix path (Improving parameter; Row 39: Productivity vs. Worsening parameter; Column 36) yielded #12, #17, #28, and #24. These principles guided the conceptual design process (see Table 1) and were further mapped to both system implementation and educational learning outcomes (Table 2). Each principle's abstract meaning was interpreted in the project context and mapped to a specific feature in the Pick and Pay system, as summarized in Table 2, followed by identifying a corresponding design challenge in the system, and finally converting that into a concrete, functional feature within the Pick and Pay cart.

Table 1. Structuring the TRIZ Technical Contradiction for the Pick and Pay Project

Observed Problem	Output	
Improving Parameter	"…easier and faster "corresponds to (33) Ease of Operation and (39) Productivity	
Worsening Parameter	"… adds complexity" corresponds to (36) Device Complexity	
TRIZ Matrix Recommended TRIZ Principles from TRIZ Table of Contradictions.	Row (33) x Column (36) Principle #32 – Colour Changes Principle #26 – Copying Principle #12 – Equipotentiality Principle #17 – Another Dimension	Row (39) x Column (36) Principle #12 – Equipotentiality Principle #17 – Another Dimension Principle #28 – Mechanics Substitution Principle #24 – Intermediary

Table 2. Contradiction Analysis and TRIZ-Based Resolutions in the Pick and Pay Project

Observed Problem	Output	
#12 Equipotentiality	Simplify flow to reduce unnecessary movement and effort	Optimized layout and screen positioning for intuitive user interaction
#17 Another Dimension	Use spatial arrangement or stacking in new configurations	Vertical arrangement of LCD and interface elements on the cart
#28 Mechanics Substitution	Replace manual tasks with electronics/automation	RFID-based scanning and automated billing functions
#24 Intermediary	Use an intermediate component to link or manage communication	Loyalty card used as an ID and payment trigger system
#32 Colour Changes	Use colour to communicate system states or guide user attention	Status indication via LCD colour or app interface

#26 Copying	Use a simplified model or mimic functionality	Simulated receipt on app mirrors printed receipt

Inventive Principal Selection and Design Ideation

In this phase, students applied the TRIZ inventive principles derived from the contradiction matrix to develop practical, inventive features for the Pick and Pay system. Each principle guided specific aspects of the system's architecture and user interaction. For instance, Equipotentiality informed the streamlined interface layout to reduce unnecessary actions, while Another Dimension led to the vertical arrangement of display components for ergonomic efficiency. Mechanics Substitution facilitated automation through the use of RFID technology, and Intermediary enabled loyalty card integration as a payment method. The principle of Colour Changes was used to signal different system statuses via the LCD and mobile app, and Copying was implemented through a simulated receipt on the mobile interface to mimic traditional printed formats.

While individual TRIZ inventive principles contributed specific design insights and creative features, the overall implementation of the TRIZ methodology in this Final Year Project aligned holistically with several Program Outcomes (POs), including PO3 (Design), PO5 (Modern Tool Usage), and PO11 (Project Management) as shown in Table 3.

Table 3. Mapping of TRIZ Principles to System Features and Learning Outcomes in the Pick and Pay Project

TRIZ Principle	Description	System Feature Implemented	Educational / PO Outcome
#12 Equipotentiality	Simplify flow to reduce unnecessary movement and effort	Optimized layout and screen positioning for ease of use	PO3 – Design of solutions considering public health, safety, societal, environmental factors
#17 Another Dimension	Use spatial arrangement or stacking in new configurations	Vertical alignment of LCD and interface elements on the cart	PO3 – Design of systems, components, or processes
#28 Mechanics Substitution	Replace manual tasks with electronics or automation	RFID-based item scanning and automated billing	PO5 – Use of modern tools for solving well-defined engineering problems
#24 Intermediary	Use an intermediate object to facilitate communication	Loyalty card functions as ID and cashless payment trigger	PO11 – Project management & finance in team environments
#32 Colour Changes	Use colour to communicate system states	LCD/app colour coding for status indications (e.g., ready, scanning)	PO5 – Integration of modern IT tools to communicate system feedback
#26 Copying	Mimic or simulate an existing function	Simulated digital receipt mirrors traditional printed receipt format	PO3 – Emulating proven models for effective design of solutions

Solution Synthesis & Prototype Evaluation

Based on the TRIZ driven design, the prototype was developed using Arduino Mega 2560, RFID RC522, an LCD display, pushbuttons, and an integrated loyalty card system acting as a debit card. Proteus software was used to simulate circuit logic before hardware implementation. The system was iteratively tested and debugged across multiple stages including breadboard prototyping, PCB layout testing, and full hardware integration. Each design decision was traced back to its corresponding TRIZ principle, enabling students to reflect on how structured inventive thinking influenced their engineering choices. This process supported the attainment of key Program Outcomes (POs) such as PO3 (design of solutions), PO5 (modern tool usage), and PO11 (project management and teamwork). Reflections gathered from the team also highlighted enhanced confidence, creativity, and systematic problem-solving outcomes that validate the pedagogical value of TRIZ in engineering education. The steps are visualized in Figure 2. As shown in Figure 3, the prototype reflects TRIZ-guided design outcomes such as streamlined interface (Equipotentiality) and component stacking (Another Dimension).

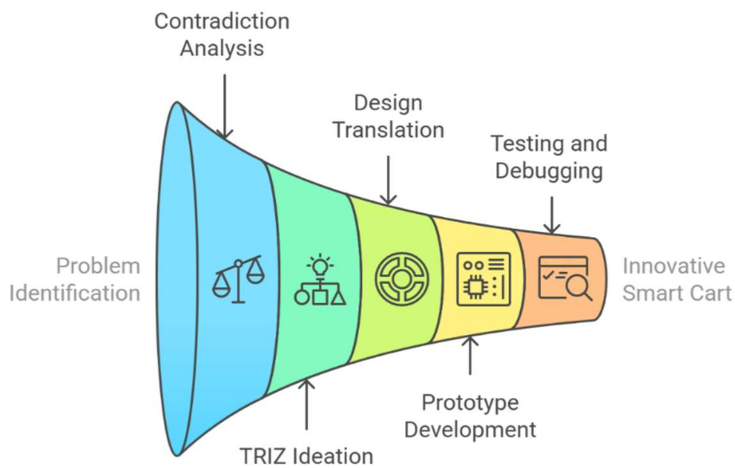

Figure 2. Pick and Pay Smart Shopping Cart Development Process

Results and Discussion

The Pick and Pay project successfully demonstrated how the structured application of TRIZ can enhance both the technical output and the cognitive learning experience in a diploma-level engineering capstone. This section presents: (i) the technical outcomes of the TRIZ-guided design, and (ii) a reflection on how TRIZ influenced students' creativity, engineering judgment, and alignment with Program Outcomes (POs).

Figure 3. Final prototype of the TRIZ-guided Pick and Pay system, developed by diploma students.

Technical Outcomes of TRIZ Driven Design

The final prototype, developed through iterative design stages and guided by TRIZ inventive principles, resulted in a functional smart shopping cart equipped with RFID-based item scanning, loyalty card payments, and a real-time billing system. Core system components included the Arduino Mega 2560 microcontroller, RC522 RFID reader, a 20x4 LCD display, and an Espresso Lite V2 Wi-Fi module. Key functionalities achieved include:

- Real-time item scanning: Enabled through Mechanics Substitution (Principle #28), allowing customers to scan items and display details immediately.
- Cashier-less checkout: Integrated with Intermediary (Principle #24) via a loyalty card that triggers payment and balance deduction.
- User interaction design: Optimized using Equipotentiality (Principle #12) and Another Dimension (Principle #17) by streamlining screen layout and stacking components vertically.
- Feedback signalling: Achieved through Colour Changes (Principle #32) for system status (e.g., scanning, payment success).
- Simulated digital receipt: Implemented via Copying (Principle #26), allowing users to view a traditional-style receipt on a mobile app.

The system was first virtually simulated and tested in Proteus for circuit validation and then implemented in hardware. Students conducted debugging across breadboard setups and printed circuit board (PCB) stages. Design decisions consistently referred to their TRIZ justification, fostering reflective engineering practice. While low-level technical problems such as wiring errors or logic bugs were resolved using conventional debugging methods, TRIZ played a pivotal role in high-level system architecture and usability innovation. This distinction illustrates TRIZ's strength as a creative strategy tool, supplemented by practical engineering methods for execution.

During the development of the *Pick and Pay* prototype, students faced several technical challenges that tested their problem-solving resilience and deepened their understanding of system integration. One common issue involved the miswiring of pushbuttons, which arose due to conflicting tutorials and wiring guides found online. This was eventually resolved through a combination of trial-and-error testing and guided consultations with instructors. Another major challenge was simulating the RFID module using Proteus software. Since the software did not natively support RFID components, students creatively mirrored RFID functionality by linking virtual pushbuttons to LEDs and buzzers, allowing them to replicate the intended system behaviour during simulations. Additionally, the team faced coding logic errors related to balance checking on the loyalty card. These bugs caused the system to incorrectly prompt "insufficient funds" regardless of the actual balance. The issue was resolved through step-by-step debugging, referencing open-source Arduino projects, and engaging in collaborative troubleshooting with peers. These experiences not only contributed to the success of the prototype but also strengthened the value of persistence, critical thinking, and teamwork in engineering practice.

The prototype effectively translated TRIZ principles into a coherent and user-centric system. The effectiveness of the solution, eliminating queues, automating payment, and enhancing user interaction, can be directly linked to the inventive strategies derived from TRIZ. It is important to note, however, that while TRIZ played a pivotal role in guiding the system's conceptual architecture and innovation features, it was not directly employed in resolving the low-level technical issues encountered during development. Challenges such as miswiring, coding bugs, and software simulation limitations were addressed through conventional engineering practices, including trial-and-error, debugging, and collaborative troubleshooting. These efforts relied on students' technical competencies and adaptability. In contrast, TRIZ contributed at the strategic level by enabling the team to design a system that was modular, user-responsive, and aligned with real-world retail needs. Thus, as depicted in **Error! Reference source not found.** the project illustrates a clear distinction between TRIZ as a tool for inventive system design and standard methods used for technical problem-solving, reinforcing the complementary roles of creative thinking and practical implementation in engineering education.

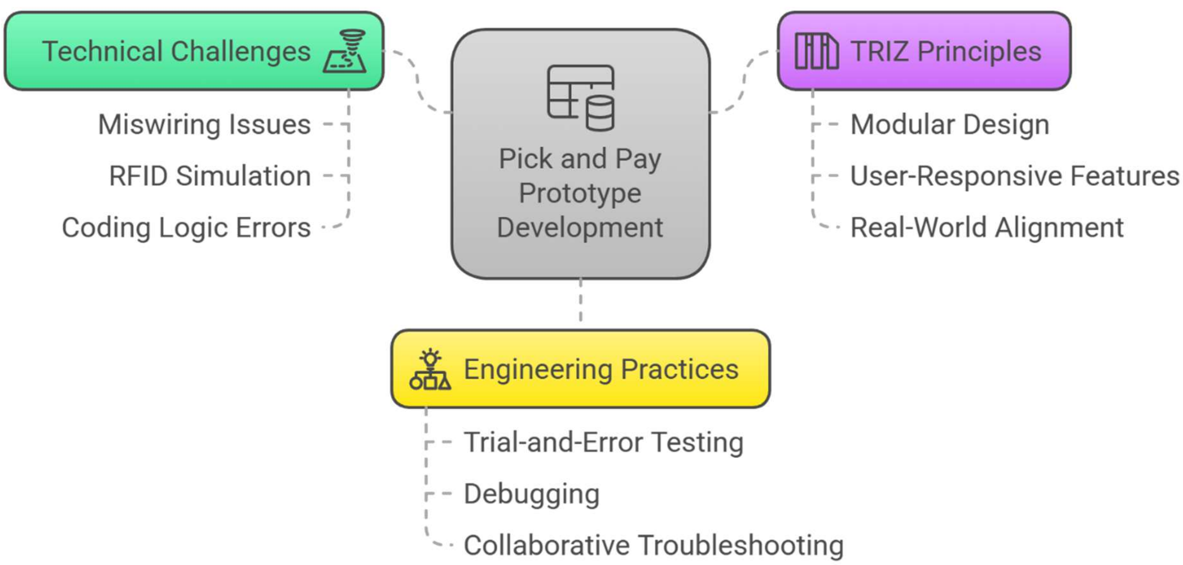

Figure 4. Encountering the Pick and Pay Prototype Development Challenges

Educational Impact and Student Reflection on TRIZ

Beyond the technical success of the Pick and Pay system, a core objective of this project was to evaluate how TRIZ influenced student learning, engineering mindset, and team collaboration. Reflections gathered through post-project interviews and design journals revealed several key themes that highlight TRIZ's pedagogical impact.

- Structured Creativity through Inventive Principles

Students consistently noted that TRIZ gave structure to their brainstorming sessions, replacing previously chaotic ideation processes with guided reasoning. The contradiction matrix and 40 Inventive Principles deck were especially useful for generating realistic yet innovative ideas.

"TRIZ helped structure our thinking. Instead of guessing features, we used contradictions to select principles and develop our design."
"Instead of vague brainstorming, we had a reason behind each design. When we used 'Mechanics Substitution,' we knew exactly why automation made sense for the cart."

- Growth in Engineering Judgment and Decision Making

The design principles helped students make informed technical choices. For instance, Equipotentiality inspired a streamlined layout that reduced unnecessary movement, and Another Dimension justified vertical stacking of interface elements to conserve space.
"Before TRIZ, we focused only on the hardware. With TRIZ, we thought about the user too—how the screen should be placed, what the flow should feel like."

- Confidence in Tackling System Complexity

As technical issues arose such as wiring faults or logic errors, students used TRIZ to revisit their conceptual approach. This shifted their mindset from linear troubleshooting to iterative refinement. "Even when we had circuit problems, we didn't give up. TRIZ made us rethink from the principle level, not just the coding."

- Enhanced Teamwork and Communication

The shared TRIZ framework helped students communicate design ideas more clearly. By referring to common principles like Intermediary and Colour Changes, teams debated features using objective language rather than subjective preferences.
"We used to argue over ideas. With TRIZ, we debated based on which principle fit best. It made discussions more productive."

- Alignment with Program Outcomes (POs)

Student activities throughout the TRIZ-guided design process demonstrated strong alignment with several key Program Outcomes (POs) outlined by the Engineering Technology Accreditation Council (ETAC). Specifically, the process addressed PO3 by enabling students to design creative, user-focused solutions, such as optimizing interface ergonomics and implementing a vertical layout for system components. The integration of modern prototyping platforms—including Arduino, RFID modules, and Proteus simulation tools—fulfilled PO5, reflecting students' ability to apply contemporary engineering tools to solve well-defined problems. Furthermore, the collaborative nature of the project, supported by structured ideation and contradiction analysis, fostered effective teamwork, planning, and resource management, thereby addressing PO11. Collectively, these outcomes affirm the educational value of embedding TRIZ into diploma-level Final Year Projects. This evidence underscores TRIZ's dual role as both a design methodology and a powerful pedagogical tool in engineering education.

Limitations and Future Work

This study is limited by its single-case context involving diploma students from one institution, which may restrict the generalizability of findings across other TVET programs or disciplines. The success of the TRIZ integration was also supported by structured guidance and mentorship, which may not be feasible in larger or resource-constrained settings. Additionally, the study focused on short-term outcomes such as prototype quality and student reflections, without assessing long-term impacts on skills retention, innovation capability, or career readiness. To address these limitations, future research should explore multi-institutional or cross-disciplinary implementations of TRIZ in TVET education. Incorporating quantitative instruments such as Likert-scale surveys, creativity rubrics, or descriptive statistics, alongside qualitative reflections would strengthen the robustness and generalizability of findings. Longitudinal studies could further provide deeper insights into the sustained educational value of TRIZ. Additionally, exploring blended pedagogical models that combine TRIZ with Design Thinking or CDIO may enhance scalability and student engagement. Finally, the development of standardized modules or facilitator toolkits could support wider adoption of TRIZ across diverse instructional contexts.

Conclusions

This study demonstrated the effectiveness of integrating the Theory of Inventive Problem Solving (TRIZ) into a diploma-level engineering Final Year Project through the development of the Pick and Pay smart shopping cart system. By applying six key TRIZ inventive principles: Equipotentiality, Another Dimension, Mechanics Substitution, Intermediary, Colour Changes, and Copying, students were able to design a user-friendly, low-cost, and fully functional prototype featuring real-time item scanning, loyalty-based payment, and automated billing.

TRIZ functioned both as a structured innovation framework and a pedagogical scaffold, enhancing students' creative thinking, systematic problem-solving, and engineering judgment. Through iterative application of TRIZ concepts, students progressed from abstract contradiction analysis to tangible, user-centred design solutions. The project clearly aligned with core Program Outcomes (POs) defined by ETAC, particularly in areas of solution design (PO3), application of modern tools (PO5), and project management and teamwork (PO11). Importantly, TRIZ encouraged reflective learning and collaborative ideation, equipping students with transferable skills essential for both academic and industry readiness. These findings support the broader adoption of TRIZ in technical and vocational education and training (TVET) curricula as a means to enhance the quality, creativity, and educational value of engineering capstone projects.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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