



OPEN ACCESS

EDITED BY

Niroj Dahal,
Kathmandu University, Nepal

REVIEWED BY

Freddy Marín-González,
Costa University Corporation, Colombia
Sagar Mani Neupane,
Kathmandu University, Nepal

*CORRESPONDENCE

Yuliana Jiménez-Gaona
✉ ydjimenez@utpl.edu.ec

RECEIVED 02 January 2024

ACCEPTED 07 October 2024

PUBLISHED 30 October 2024

CITATION

Vivanco-Galván O, Castillo-Malla D,
Suconota E, Quizphe R and
Jiménez-Gaona Y (2024) Enhancing
mathematical function understanding in
university students: a comparative study of
design thinking vs. traditional teaching
methods.
Front. Educ. 9:1364642.
doi: 10.3389/feduc.2024.1364642

COPYRIGHT

© 2024 Vivanco-Galván, Castillo-Malla,
Suconota, Quizphe and Jiménez-Gaona. This
is an open-access article distributed under
the terms of the [Creative Commons
Attribution License \(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use,
distribution or reproduction in other forums is
permitted, provided the original author(s) and
the copyright owner(s) are credited and that
the original publication in this journal is cited,
in accordance with accepted academic
practice. No use, distribution or reproduction
is permitted which does not comply with
these terms.

Enhancing mathematical function understanding in university students: a comparative study of design thinking vs. traditional teaching methods

Oscar Vivanco-Galván¹, Darwin Castillo-Malla²,
Edgar Suconota³, Rolando Quizphe³ and
Yuliana Jiménez-Gaona^{2*}

¹Departamento de Ciencias Biológicas y Agropecuarias, Universidad Técnica Particular de Loja (UTPL), Loja, Ecuador, ²Departamento de Química y Ciencias Exactas, Universidad Técnica Particular de Loja, Loja, Ecuador, ³Departamento de Ciencias de la Educación, Universidad Técnica Particular de Loja, Loja, Ecuador

Mathematical education requires innovative didactic strategies to enhance the understanding and application of mathematical concepts, as traditional teaching methods often lack relevance. This methodology aims to develop a problem-solving scientific approach called design thinking as a strategy for learning mathematics functions. The study was applied to a sample of 138 students of biochemical, biological, and industrial engineering careers attending the first academic cycle at the Faculty of Natural and Exact Sciences of the Particular Technical University of Loja-Ecuador. The methodology uses a quasi-experimental design with a convenience sampling method. All participants were divided into a control group (C, D, K) and an experimental group (P, Q, R). Knowledge, skills, perceptions, and engagement were measured through pretest, posttest, workshop, rubric, project, and survey instruments. The pretest results indicate that both groups had similar knowledge of mathematical functions (*pretest* mean experimental group: 1.42/2 and mean control group: 1.55/2). Moreover, after applying design thinking strategy to the experimental group, variables *questionnaire*, *project*, and *workshop* show statistical differences ($p < 0.001$) between groups related to the traditional learning strategy, increasing the experimental group's score in the project (*posttest* mean experimental group: 1.62/2 points, and mean control group: 1.65/2). The survey opinion indicates that 53.5% of the experimental group highlighted the project's development as positively impacting their academic training. In conclusion, problem-solving design thinking using scientific projects as a mathematical function learning strategy contributes to improving the comprehension of polynomial functions and developing mathematical competencies, abilities, and skills to generate tangible solutions for real problems.

KEYWORDS

mathematical education, teaching-learning strategies, scientific problem solving, didactic strategies, practical application of mathematical

1 Introduction

Mathematical education constantly demands new didactic strategies that promote the understanding and practical application of mathematical concepts, as various authors point out that mathematics teaching often needs more relevance (Smith and Jones, 2023; Swan, 2020). Therefore, recent research highlights that university curriculum design must develop generic competencies (Problem-Solving Skills, Critical Thinking, and Communication Skills) and specific competencies (Mathematical Reasoning and Numeracy) strengthened by Mathematical Didactics, allowing students to creatively model reality in their careers (Brown et al., 2024).

In this context, the evolution of educational models emphasizes the importance of didactic strategies in teaching mathematics. According to Vargas-Hernández and Vergara (2022), they emphasize the importance of didactic strategies for meaningful mathematics and professional training learning. As defined by Hernández et al. (2021), didactic strategies are tools teachers use to facilitate the autonomous construction of knowledge, considering that a student-centered approach promotes dynamic learning based on developing learning skills (Andrango Baculima, 2022).

Other studies (Ting et al., 2023; Johnson and Lee, 2021; Verganti et al. 2021) highlight innovative approaches that promote students' active participation and critical thinking. The didactic strategies mentioned include collaborative and meaningful learning and active methods such as the use of ICTs, Project-Based Learning (PBL), Flipped Learning, Case Studies, Gamification, and Design Thinking (DT), among others (Bhatt and Chakrabarti, 2022; Brown, 2009; Prince, 2004), which are essential in enhancing mathematics education.

These methods actively engage students, fostering critical thinking, problem-solving, and a more profound comprehension of mathematical principles. *Collaborative learning* encourages students to work together, discussing and solving problems, which deepens their understanding through peer explanations and diverse perspectives. *Problem-Based Learning (PBL)* involves students addressing real-world issues, helping them apply mathematical concepts in practical contexts, thus reinforcing their knowledge. DT emphasizes creative problem-solving, where students prototype and iterate on solutions, leading to innovative approaches to applying mathematical concepts, promoting active learning that fosters practical solutions, as stated by Patiño et al. (2023) and Mduwile and Goswami (2024). DT involves several stages (empathize, define, ideate, prototype, and test) crucial for solving complex problems and obtaining feedback (Balcaitis, 2019). These stages drive innovation and the resolution of academic and real-world challenges, promoting PBL and creative and systemic thinking in problem-solving. These active learning methods immerse students in hands-on activities, making the learning process more engaging and less abstract (Brown, 2009; Prince, 2004).

However, the problem of mathematical didactics in pedagogical praxis, the disciplinary complexity of mathematics, and the development of meaningful learning are interconnected issues in mathematics education (Brown, 2009). Mathematical didactics deals with how mathematical concepts and skills are effectively taught and learned. In pedagogical praxis, this problem manifests in several ways: (i) Curriculum Design balances between theoretical knowledge and practical application (Artigue, 2009; Skovsmose, 2012). (ii) Innovative Teaching Methods (Guo et al., 2020; Jiménez and Castillo, 2018). (iii) Formative assessments that help in adjusting teaching methods and

summative assessments that evaluate overall learning (Jiménez et al., 2018). And (iv) Teachers must find ways to make mathematics relevant and interesting to foster a positive attitude towards the subject and to engage the student (Black and Wiliam, 1998).

Thus, mathematics is inherently complex, and this complexity is reflected in its didactics, which involves abstract thinking and concepts that can be difficult to grasp (Boaler, 2022). Effective didactics must address these connections to help students build a cohesive understanding of mathematics, involving a progressive learning process from basic to more complex concepts (Sfard, 2017). Didactics must ensure that each stage of learning builds on previous knowledge, which can be challenging given the varying pace at which students learn (Andrews and Hatch, 2019).

Finally, teaching mathematics involves developing students' problem-solving and critical-thinking skills. Didactics must address how to cultivate these skills alongside teaching specific mathematical content (Schoenfeld, 2021). It can help students to explain their reasoning, make connections between different topics, and apply their knowledge to novel problems, and are actively involved in their learning process through exploration, discussion, and reflection.

While active learning methods provide significant advantages for teaching mathematics by fostering deeper understanding and engagement, several gaps remain that must be addressed to fully leverage their potential in strengthening disciplinary didactics. These include better aligning these methods with the specific needs of mathematics education, enhancing teacher training, and developing more suitable assessment tools.

This gaps in the application of DT strategy are often generalized and may not always align with the structured and sequential nature of mathematics, sometimes neglecting the necessity for rigorous practice and mastery of fundamental mathematical skills (Anderson and Shattuck, 2020). Second, effectively implementing active learning methods requires teachers to be proficient not only in these approaches but also in how to apply them specifically within the context of mathematics. However, there is often a gap in teacher training for these specialized applications (Darling-Hammond et al., 2021).

Traditional assessment methods also fall short in capturing the full range of skills and understanding developed through active learning, especially in mathematics, where standardized tests tend to emphasize rote memorization and procedural fluency (Brookhart, 2017). Additionally, active learning methods can be time-consuming, and the pressure to cover a broad curriculum can limit the extent to which these methods are utilized (Knight, 2022). Implementing approaches like DT often requires additional resources, such as time for planning, materials for prototyping, and flexible classroom environments, which may not be readily available in all educational settings (Brown, 2020). However, this methodology combines analytical and creative thinking to solve problems effectively. It surpasses traditional education by stimulating student participation and developing skills such as group interaction, autonomous learning, and time management (Liedtka, 2017).

This didactic research evaluates how the DT-based strategy influences the learning of mathematical functions and their practical application in developing scientific projects within different professional contexts and considering that the DT strategy applied to problem-solving using mathematical functions facilitates understanding and motivates students to foster problem-solving skills, contributing to a deeper appreciation of mathematics as a discipline, and to the advancement of science by introducing and validating a

novel approach to teaching mathematics, specifically polynomial functions, through the application of DT.

The study's findings have several key contributions and impacts such as an innovative methodology, and offers empirical data demonstrating the effectiveness of DT compared to traditional teaching methods. The research aligns with emerging educational paradigms that emphasize student-centered learning and problem-solving. By integrating DT into mathematics instruction, the study supports the shift towards more interactive and engaging teaching methods.

The significant improvement in the experimental group's post-test scores underscores the relevance of incorporating DT strategy into educational practices. This approach not only improves academic performance but also fosters critical thinking and problem-solving skills. The direct beneficiaries of this research are the 100 university students from biochemical and industrial engineering programs at the Particular Technical University of Loja in Ecuador, and indirectly beneficiaries are educators, and academic institutions to whom this study provides evidence-based insights into effective teaching methodologies. This can influence curriculum design and pedagogical strategies, ultimately enhancing mathematics education on a broader scale.

Finally, the competencies and skills acquired by students to work in teams and the ability to solve problems must also be assessed using different techniques (logs and rubrics), which allow students to visualize their progress. The evaluation of the DT strategy is an integral process that must address all aspects of learning, and a variety of methods and tools must be used to assess the process and competencies of the students. This comprehensive evaluation, supported by Jiménez-Gaona and Vivanco-Galván (2024), addresses the entire learning process, highlighting the development of competencies in problem-solving and teamwork.

1.1 Related work

Jiménez-Gaona and Vivanco-Galván (2024) proposed a PBL as a promising approach to enhance mathematics learning concepts in higher education. Here, teachers provide guidance and support to PBL implementation, which results shows significant differences ($p < 0.001$) between the experimental and the control group. Concluding that the teaching of mathematics should be oriented to the development of competencies, abilities, and skills that allow students to generate real solutions and broaden their vision of the applicability of their knowledge using new learning strategies.

Also, Krajcik et al. (2023) and Miller and Krajcik (2019) describes key characteristics of PBL in STEM education such as driving questions, learning goals, and scientific practices. Their study explored how these principles are implemented in real-world settings, focusing on collaboration, technology use, and the creation of artifacts. Offering a process for designing a curricular system that enhances how students learn science as a progression toward sophisticated practice of usable knowledge by focusing on coherence, depth, and motivation.

This aligns with the work presented by and Gómez-Pablos et al. (2017) were the impact of PBL on Mathematics Learning was explored by a literature review, highlights how PBL has been used to develop mathematical thinking and problem-solving skills. For example, Holmes and Hwang (2016) explored PBL in secondary mathematics education and found that it positively impacts student performance by making learning more engaging and meaningful, emphasizes the connection between PBL and the application of mathematics and

science, particularly in developing skills and fostering a deeper understanding of mathematical concepts through hands-on, real-world projects using mathematical knowledge to solve specific problems and in practical situations.

Lazic et al. (2021) examines the influence of PBL on student achievement in elementary mathematics education, revealing that students engaged in PBL tend to show higher achievement levels in mathematics.

According to the previous related work on innovative didactic strategies that occur in the classroom and are part of the teaching practice, it is possible to discover new ways, tools, and strategies that allow us to achieve better student academic results and quality education according to Sustainable Development Goals.

In the educational community of our country, at the university level, we are concerned about the lack of interest and attention in the learning of mathematics of students, which is why there is an essential factor in raising the quality of education at the national level, which is the change in the pedagogical practice of educators, as demonstrated by various institutions and organizations dedicated to educational research.

In our province, teaching at the primary and secondary level has been somewhat affected in terms of teaching-learning strategies since most teachers do not have knowledge of these strategies and, therefore, do not implement them in the classroom, which represents a problem in education, since students are not developing critical thinking, problem-solving skills. There is a great diversity of factors at the local level, specifically in our educational institution. For example, university teachers must learn about using TICs based on AI, collaborative, and immersive learning simply because they focus more on other aspects than implementing these strategies.

Thus, according to the previous mentioned the aims of this study are: (i) Develop a problem-solving scientific approach using DT as a strategy for teaching-learning mathematics functions during the first academic cycle of "Fundamentals of Mathematics" subject in Biochemistry, Biology, and Industrial Engineering UTPL careers from October 2022–February 2023. (ii) Evaluate the knowledge of the mathematical functions through scientific proposals and entrepreneurship projects before and after implementing the problem-solving-based DT strategy. (iii) Analyze the statistical results obtained from the evaluation instruments and demonstrate the influence of the strategy on learning mathematical functions.

2 Materials and methods

In this deductive study, we hypothesized that problem-solving learning based on design thinking is a good didactic strategy on teaching mathematical functions and has a positive impact in mathematical functions learning. The main steps for developing this methodology are detailed in Figure 1.

2.1 Methodology approach

This study follows a positivist paradigmatic framework that is based on the idea that reality is objective and can be measured, quantified, and observed directly through the hypothetic-deductive method with the formulation of hypotheses that can be tested and refuted through empirical evidence (Ho: Mathematic Teaching based on the DT strategy does not significantly influence in the learning of

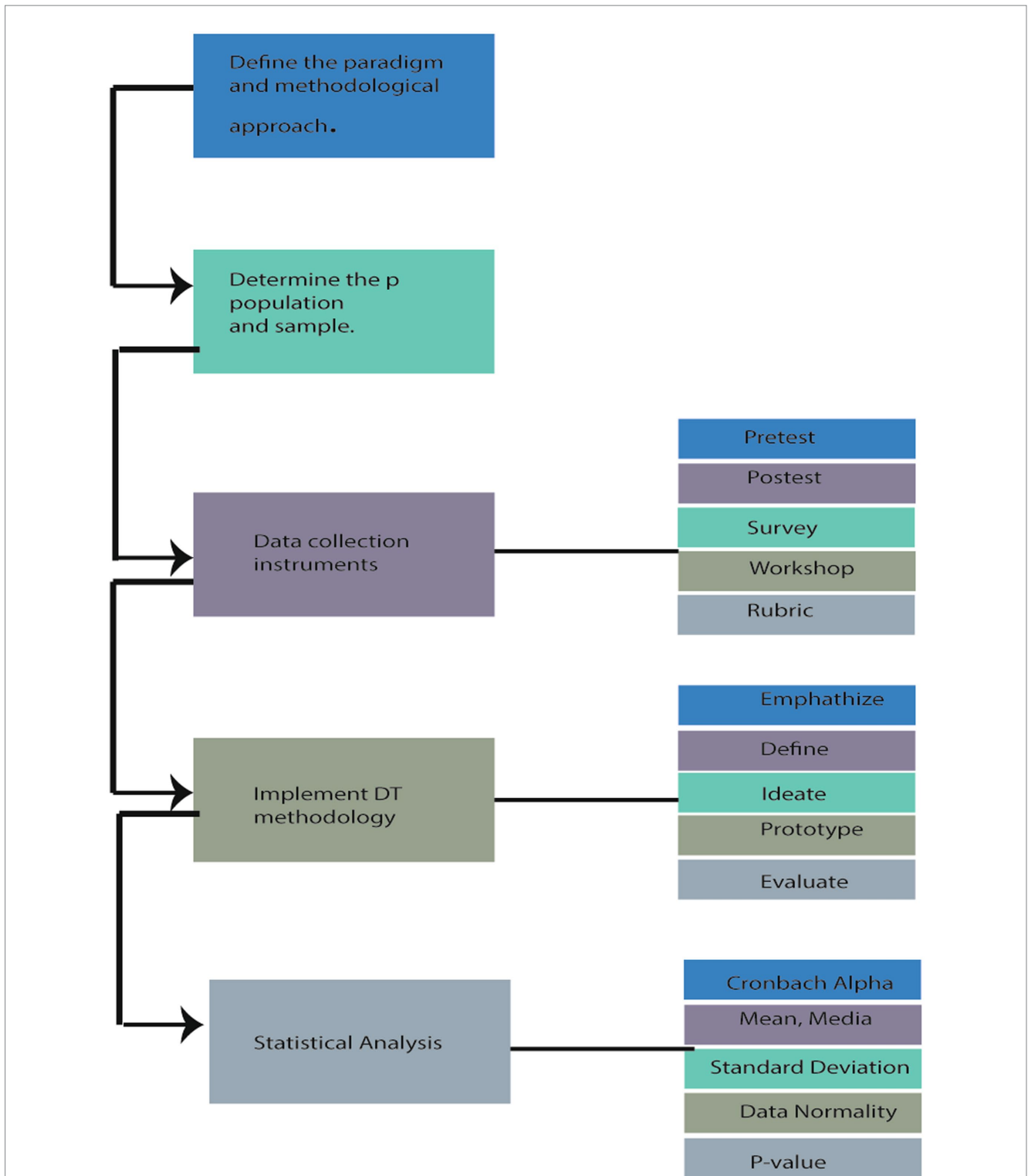


FIGURE 1 Steps in the implementation of the design thinking methodology. Created in Biorender.

mathematical functions. Ha: Mathematic Teaching based on DT strategy significantly influences the learning of mathematical functions), controlled experiments, and quantitative data collection.

It also presents a constructivist and quasi-experimental design that asserts that individuals actively construct knowledge from their interactions with others because they learn through interaction and

collaboration with their environment. The quasi-experimental design was selected especially because is relevant in real-world settings and are commonly applied in education. The professor can control the methodological treatment with scientific rigor using variables, statistical analysis which can help isolate the effect of an independent variable on a dependent variable, despite the absence of randomization.

And becomes a valuable and methodologically sound way of drawing inferences in educative settings, particularly when accompanied by rigorous.

Finally, an interpretivist framework was applied using an interview to understand how a group of students interpret their experiences and emotions when developing projects. The aim was to discover patterns of behavior and subjective meanings, which could provide intriguing insights (Hernández-Sampieri and Mendoza, 2020).

2.2 Population and sample

The project was developed at the Universidad Técnica Particular de Loja (UTPL), with a population of 138 students of “Mathematical fundamentals” Subject, which has pedagogical curriculum focus on mathematical function such as polynomial, rational, and irrational algebraic functions, and special functions such as exponential, logarithmic, trigonometric, inverse and absolute value, studied during the second semester.

Inclusion criteria: Student’s must be between 18 and 20 years old, first-year enrollment at Faculty of Natural and Exact Sciences, and belonging to Biochemistry-Pharmacy, Biology and Industrial Engineering (selected by the professor and number of students lower than 33) and who enrolled in the “Mathematical fundamentals” subject, during the academic period from October 2022 to February 2023.

Exclusion criteria: Student’s enrollment in other academic cycles (from second to ten levels), other technical careers and enrolled in non-mathematical subjects.

Profile 1: University students aged 18–20, enrolled in first academic cycle enrollment at Faculty of Natural and Exact Sciences and belonging to Biochemistry-Pharmacy, Biology and Industrial Engineering, with varying levels of proficiency in mathematics.

Profile 2: Mathematic teachers with at least 15 years of teaching experience, who have used active learning methods in the past.

The sample used in the project consisted of 138 students (72 experimental and 66 control) of Biochemistry, Biology and Industrial obtained from the total population, see Table 1. The sample size was calculated using the Equation 1 (Cronbach, 1951)

$$n = \frac{Z^2 * PQN}{E^2(N - 1) + Z^2 * PQ} \tag{1}$$

TABLE 1 The distribution of the sample.

Degree	Classroom	No. of students	Group
Biochemistry	Q	16	Experimental
Biology	P	23	
Industrial Engineering	R	33	
Biochemistry	C	22	Control
	K	22	
	D	22	
Total		138	

Where, n =Sample size, N =Population size (212 students), Z =Confidence coefficient, being 1.96; at 95% confidence level, P =Probability of success (0.50), Q =Probability of failure (0.50), Margin of error (0.05) (Jung, 2014).

2.3 Variables: dimension and operationalization

The variables and their respective measures are described in Table 2, where the independent variable is: Teaching strategies DT and the dependent variable is: Influences on students’ learning of mathematical functions.

2.4 Research design

This study evaluates learning based on DT in the teaching-learning of mathematical functions, using a positivist approach and a quasi-experimental methodology. The empiricist, or positivist, approach is based on observation and objectively measuring reality. In this context, our educational research is relevant because it promotes the collection of quantifiable data through surveys and experiments. It is crucial to objectively evaluate the effectiveness of pedagogical strategies such as DT in mathematics teaching. Furthermore, this approach facilitates the control of external variables, ensuring that any observed changes in outcomes (e.g., student learning) can be attributed with greater certainty to the intervention of the DT teaching strategy. And the results obtained from this didactic research can be replicated and generalized to other contexts.

The quasi-experimental design is used to randomly assign subjects to the control and experimental groups, following methodological rigor to analyze the effect of an intervention.

In this case, when applying DT as a strategy in teaching mathematics, the quasi-experimental design allowed us to use pre-existing groups but apply techniques to minimize bias and guarantee the study’s validity, working within the sample size limitations. Furthermore, this design allows us to compare the performance of students who have been exposed to the DT strategy with those who have not (control group). Thus, it is possible to measure the impact of the intervention objectively as this type of design reflects more accurately the complexity of the actual educational environment, making the results obtained more applicable to everyday situations, promoting creative and student-centered problem-solving.

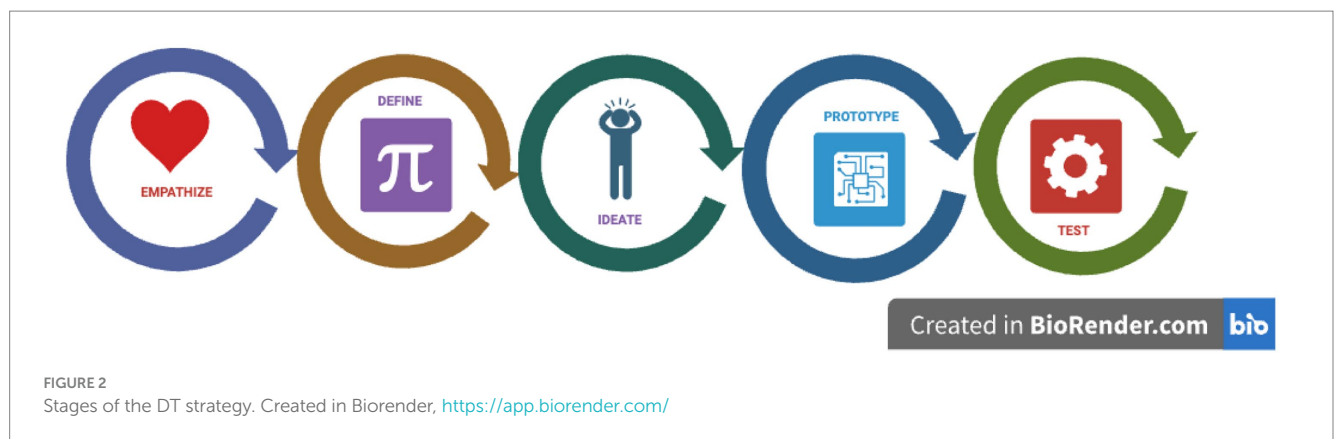
Therefore, the use of an empiricist approach and a quasi-experimental design is justified by its ability to provide objective and valuable data on the effectiveness of DT in mathematics teaching, within the practical constraints of the real educational environment, ensuring its applicability.

2.4.1 Design thinking process mapping

The teacher gives the rules of the project, conforms to random work teams, and provides direct instruction before starting a project using DT strategy. The projects focus on resolving issues at both local and national levels. Then teacher follows the academic plan contents and explains the mathematical function concepts, emphasizing developing practical exercises and workshops based on polynomial,

TABLE 2 Description and measurement of variables in the operationalization study.

Variable	Specific objective	Operational concept	Dimension	Indicators	Instrument per variable
Academic notes	Determine the level of prior knowledge about mathematical functions in first-semester students of Biochemistry and Industrial Engineering at UTPL during the academic period October 2022–February 2023.	Designing and implementing didactic strategies focused on meaningful learning and aligned with the developed context can generate better results in professional training.	Understand the mathematical thinking of first-semester students at UTPL.	Knows the concept and properties of mathematical functions. Represents mathematical models with linear, quadratic, polynomial, exponential, and logarithmic functions.	Pre-test, post-test, rubric, workshops, and questionnaires.
Projects evaluation	DT is characterized by encouraging them to develop their own solutions, apply concepts and theories in different situations, and involve both teachers and students in analysis and discussion to achieve concrete results.	Develop design thinking through the following steps: empathize, define, ideate, prototype, and test.	Correctly apply linear, quadratic, polynomial, exponential, and logarithmic functions to represent real-world mathematical models that help find reliable solutions to complex problems.	Student reports, Continuous assessment rubrics, Academic notes from project presentations and evaluations, Academic notes from post-learning evaluation.	Rubric
Survey data	Evaluate the knowledge acquired about mathematical functions after the application of the DT-based PBL.	Analyzing the results obtained from evaluation instruments and the application of the PBL strategy in learning mathematical functions.	Placing assessment at the center of the teaching and learning process has a profound impact on what, how, why, and how much our students learn and study.	Use tools to evaluate the integration of learned content and the viability of projects to obtain quantitative results. Evaluate the knowledge acquired by students on the topics of mathematical functions.	Satisfaction survey



rational, transcendent (exponential, logarithmic, trigonometry) and special functions (inverse, absolute value, discontinuous functions) (Aguilar Márquez, 2015; Demana et al., 2007).

The DT strategy followed by students consists of several phases: empathize, define, ideate, prototype, and testing (Chairil Hikayat et al., 2020; Dym et al., 2005), see Figure 2.

In education, DT serves as a bridge between theoretical knowledge and practical application. It involves a process that encourages students to engage deeply with content through the following stages:

- 1 Empathy: Multidisciplinary groups were formed to propose scientific projects using creative thinking techniques. They then conducted a bibliographic review to understand the needs

and challenges faced by learners or the problems they are trying to solve. The student list is used as a data collection technique.

- 2 Define: This stage involves a collaborative effort to clarify the problem or learning objective, often through group brainstorming sessions. The academic report is used as a data collection technique.
- 3 Ideate: Generating a wide range of ideas or solutions without constraints, encouraging creativity, and applying mathematical functions as part of the solution in designing projects and prototypes. The proposed solutions focused on biotechnology contributions to sustainable development goals. The academic report is used as a data collection technique.

- 4 Prototype: Building tangible representing possible solutions demonstrating mathematical conceptual models understanding. These innovative proposals were evaluated using a rubric with a scale (0–2) in different ranges: 1.70–2.00: Excellent; 1.30–1.65: Good; 0.90–1.25: Fair; 0.50–0.85: Poor; Less than 0.50: Very poor. [Table 2](#) presents several projects and innovative solutions to problems raised in phase 2 and 3, based on clarity, foundation, feasibility criteria, and significant contribution to sustainable solutions in the biochemical and industry process, see [Appendix E](#).
- 5 Test: Experiment with these prototypes, receive feedback by UTPL teachers and experts in the area, and persistently refine ideas or solutions in an iterative process. The rubric is used as a data collection technique.

2.5 Diagnostic and evaluation of instruments

Qualitative and quantitative data were used to measure changes to assess the impact of the intervention and are used as evidence of the intervention's effectiveness. These instruments were applied to control and experimental groups, and are described as follows:

Expert's Evaluation Rubric: The pretest and post-test instruments were designed and validated by UTPL experts in mathematics education using high-quality sources ([Guba and Lincoln, 2018](#)) (see [Appendix A](#)). A pilot test was conducted, where mathematical function questions and problems were identified, as well as the clarity and functionality of the instrument. The instrument is administered to a small representative sample of the target population. Feedback is collected on the clarity of the questions, the time required to complete the instrument, and difficulties encountered. Adjustments are made to the instrument based on feedback to improve clarity, eliminate ambiguity, and ensure that it is understandable and applicable to the broader target population.

Pretest: A questionnaire of 20 multiple-choice including questions related to functions definitions, domain and range, graphical representations, types of functions, and practical applications. This instrument allowed the assessment of prior mathematical function knowledge as a reference to analyze the impact of the DT didactic strategy in the posttest (see [Appendix B](#)) applied to both groups.

Posttest: A questionnaire of 20 multiple-choice applied to both groups, which aimed to measure the knowledge about topics related to mathematical functions after applying the DT strategy concerning traditional learning (TL) (see [Appendix B](#)). The Quizz tool¹ and UTPL's virtual learning environment (CANVAS platform²) were used to answer the questionnaires and evaluate the teaching-learning process, and to obtain quantitative and correlational approach to obtain precise data ([Guba and Lincoln, 2018](#)).

Project Evaluation Rubric: The projects presented by the experimental group are evaluated by a rubric. This rubric considers aspects such as clarity, organization, visual resources, and argumentation each criterion is assessed on a scale that ranges from

“Needs Improvement,” “Acceptable” and “Optimal.” The final grade for the project is based on these evaluations, with the Academic-Scientific section contributing 70% (Definition and description of the problem, solution design, solution development, results analysis, discussion and conclusions, formal documentation) and the Professional Development section contributing 30% (presentation, clear explanation of the proposed solution design, oral expression quality) of the total score (see [Appendix C](#)).

Survey: The opinion survey is applied to the experimental group through Google Forms to identify students' opinions about the DT strategy applied in the classroom and consists of 16 Likert-type questions. The reliability of the instrument was evaluated with Cronbach's Alpha coefficient (>0.7 suggests a high level of internal consistency), as highlighted by [Jiménez Gaona \(2021\)](#), who underscored the importance of this metric in measuring the internal consistency of the data (see [Appendix D](#)). Finally, the reliability and validity of the questionnaires and survey instruments were evaluated using Cronbach's alpha coefficient ([Cronbach, 1951](#)).

2.5.1 Statistical data analysis

A descriptive statistical analysis was performed using the software R version 4.1 ([R Core Team, 2021](#)) to tabulate and compare the data collected from the instruments (pre test, workshop, questionnaire, project or test and post test) between the experimental and control groups. The nonparametric Kruskal-Wallis analysis was carried out to test the statistical significance between the experimental and control groups obtained from the questionnaire, workshop and project, followed by the Mann-Whitney test. The descriptive analysis data were expressed as mean \pm standard deviation (SD), standard error (SE).

3 Results

A total sample of 138 students of Biochemistry, Biology and Industrial Engineering participated in the project (72 students below to experimental group: DT and 66 students below to control group: TL). The most relevant results from the DT strategy and its application in mathematical functions learning are presented below.

3.1 Design thinking strategy

The DT strategy was applied to develop projects focused on resolving issues at both local and national level. The experimental group developed projects based on mathematical functions, applying DT strategy for each proposed ([Table 3](#)).

3.2 Statistical data analysis

Descriptive statistics were obtained from the mean academic scores corresponding to the strategy applied to each group.

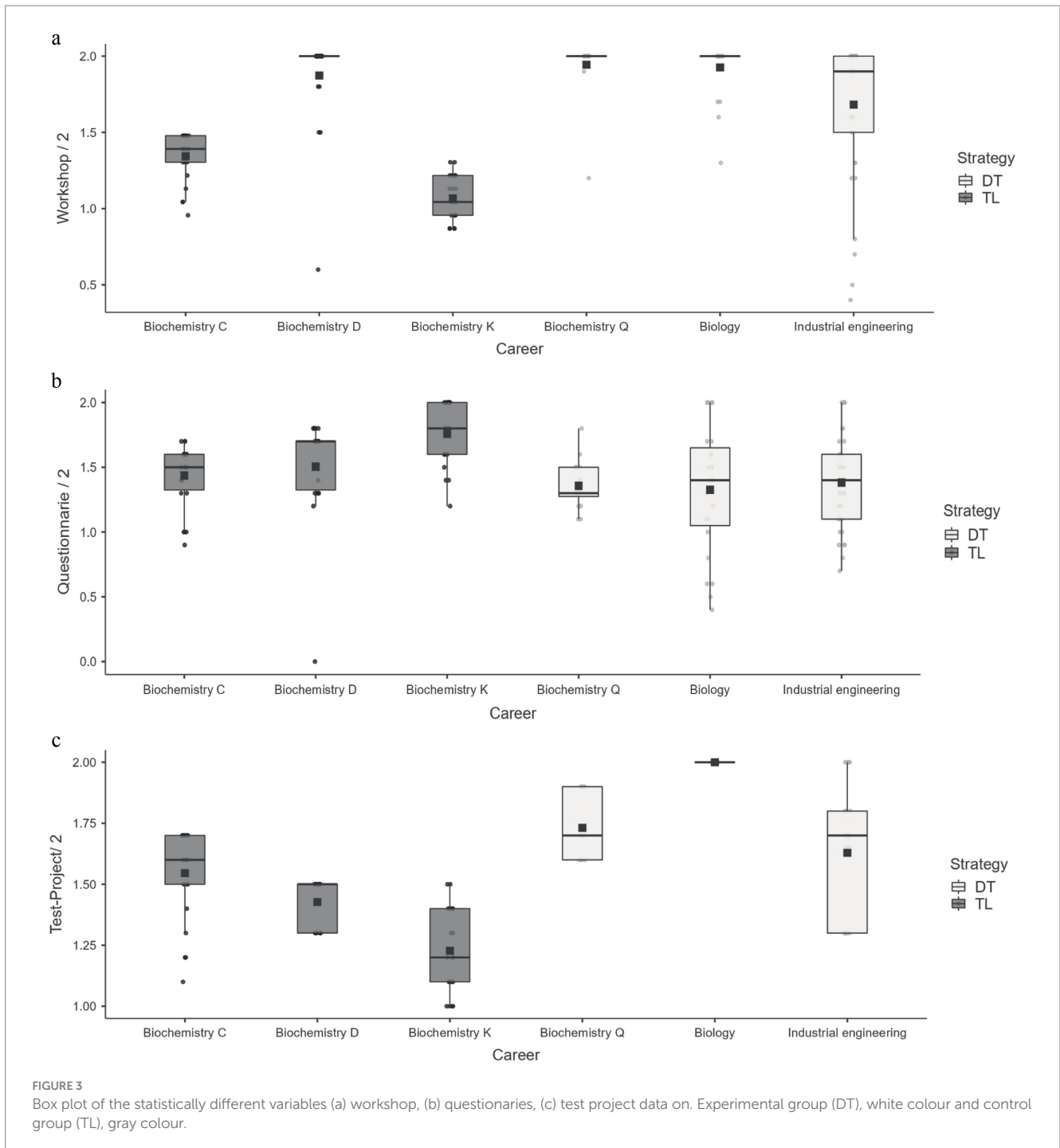
The descriptive statistical method was used to evaluate the data obtained from the experimental (DT) and control (TL) groups after applying various instruments (pre-test, post-test, questionnaire, project, test, workshop) to assess their knowledge of mathematical functions. At the beginning of the research, both groups had similar levels of basic knowledge in mathematical functions, as indicated by the pre-test

1 <https://quizizz.com>

2 <https://eva2.utpl.edu.ec/loginutpl/index.php>

TABLE 3 Application of mathematical functions in scientific projects of innovation and entrepreneurship.

Projects title	Score (0–2)	Application	Equation
Eco-friendly eyeglass frames made from recycled plastic.	2	Linear function in offer-demand of products.	Offer equations. $q_A = 7 - p_A + p_B$ $q_B = 24 + p_A - p_B$ Demand equations $q_A = 3 + 4p_A + 2p_B$ $q_B = -5 - 2p_A + 4p_B$ Where A and B are the products, q_A and q_B are the quantities produced and sold of A and B respectively, p_A and p_B are their respective prices.
Extraction of collagen from tilapia scales for wound healing in animals.	1,9	Production cost of p collagen units	$c = (3q \ln q) + 12$ Where, $q = 100$ units
Hydraulics branch.	1,8	Pascal's principle	$P = F \cdot A$ Where, F=Force; P=Pressure, A=Area
Bio-wood from recycled bioplastics.	1,7	Offer-demand	Total, income equation $y_{ix} = 20.5\sqrt{q + 4} - 41$ Total, cost equation $y_{ix} = 0.02q^3 + 10.4$ Where, q is the number of units produced as the number of units sold.
Bioremediation of polluted water with cabuya leaves.	1,7	Water pollution	Environmental supply equation describes the levy per ton, L (dollars) as a function of total pollution, p (in tons per km ²) for p ³ 0.2295 Environmental demand equation describes the cost per ton of abatement as a function of total pollution for p > 0.
Biodegradable materials from mushroom mycelium (ganoderma)	1,65	Biology application using logarithmic functions	Where, the population of mushroom mycelium at instant t is represented by $N = N_0 \frac{t}{(2k)}$ Where N ₀ is the number of cells in t=0 and k is a positive constant. The time required to reach a total population is $t = k \log_2 \frac{N_1}{N_0}$
Bio-degradable and environmentally friendly products from cassava starch.	1,6	Function in parts to evaluate bacterial growth for biodegradable product development.	$t = f(T) = \begin{cases} \frac{1}{24}T + \frac{11}{4} & \text{si } 30 \leq T \leq 36 \\ \frac{4}{3}T - \frac{175}{4} & \text{si } 36 < T \leq 39 \end{cases}$ Where t is the time in hours taken for the number of bacteria to double as a function of the culture's temperature T (or centigrade).
Manufacture of toothbrush from recycled plastic.	1,3	Compound interest using exponential function	$A = P \left(1 + \frac{r}{n}\right)^{nt}$ Where, A is the total interest, P is initial value, r is the rate in decimals, n is the number of periods and t is the time.
Production of a beverage through the process of fruit distillation.	1,3	Logarithmic functions Cost of producing q units of this beverage	The cost of producing q units of this beverage is given by the equation $c = (3q \ln q) + 12$ A manufacturer's supply equation is $p = \log \left(10 + \frac{q}{2}\right)$ Where q is the number of units offered at the unit price p
Protein natural for lactose intolerant people "NATURAL PROTEIN."	1,5	Square function in production.	$q = f(m) = \frac{(40m - m^2)}{4}$ Where, q is the total number of production units per day, m is the function of the number of employees. The total revenue, r, which is received from the sale of q units, is given by the function g, where $r = g(q) = 4$



variable. The experimental group had a mean value of 1.42/2 points, while the control group had a mean value of 1.55/2 points. However, after applying the didactic strategy DT to the experimental group, the post-test showed a significant improvement achieving a mean value of 1.62/2 points and a mean value of 1.65/2 points in a control group with traditional learning. Despite this improvement, the final scores did not show a statistical difference between the six classes of both groups, as tested by the Kruskal-Wallis test, as shown in Table 4.

The variables questionnaire, test-project, and workshop show statistical differences ($p < 0.001$) that are related to the type of strategy

analyzed (DT or TL). For the variable's questionnaire and workshop, the effect size was small, whereas for the variable test-project, the effect size was medium, indicating that this academic activity represents an improvement in the learning of mathematical functions (Table 4).

A non-parametric analysis was developed, the variable questionnaire, test-project and workshop show statistical differences that are related with the strategy type analyzed.

Thus, DT as a teaching-learning strategy for functions slightly increases the experimental group's score in the project. The application of the project showed significant statistical differences to the variable

TABLE 4 Descriptive statistical analysis of instruments used for evaluation in both groups: traditional learning (TL) and design thinking (DT).

	Career	Strategy	Pre test/2	Post test/2	Questionnaire/2	Test-project/2	Workshop/2	Final score/10
N	Biochemistry C	TL	22	22	22	22	22	22
	Biochemistry D	TL	22	22	22	22	22	22
	Biochemistry K	TL	22	22	22	22	22	22
	Biochemistry Q	DT	16	16	16	16	16	16
	Biology	DT	23	23	23	23	23	23
	I engineering	DT	33	33	33	33	33	33
Mean	Biochemistry C	TL	1.60	1.77	1.44	1.55	1.34	8.54
	Biochemistry D	TL	1.39	1.47	1.50	1.43	1.87	7.67
	Biochemistry K	TL	1.65	1.71	1.76	1.23	1.07	8.57
	Biochemistry Q	DT	1.49	1.57	1.36	1.73	1.94	8.10
	Biology	DT	1.56	1.80	1.33	2.00	1.93	8.60
	I engineering	DT	1.28	1.52	1.38	1.63	1.68	7.49
EE	Biochemistry C	TL	0.04	0.04	0.05	0.04	0.04	0.15
	Biochemistry D	TL	0.06	0.09	0.08	0.02	0.07	0.19
	Biochemistry K	TL	0.04	0.03	0.05	0.04	0.03	0.16
	Biochemistry Q	DT	0.13	0.11	0.05	0.03	0.05	0.25
	Biology	DT	0.06	0.05	0.10	0.00	0.04	0.14
	I engineering	DT	0.07	0.07	0.06	0.05	0.08	0.21
SD	Biochemistry C	TL	0.18	0.18	0.25	0.19	0.16	0.73
	Biochemistry D	TL	0.28	0.43	0.39	0.10	0.32	0.90
	Biochemistry K	TL	0.19	0.15	0.24	0.17	0.15	0.74
	Biochemistry Q	DT	0.54	0.43	0.19	0.12	0.20	0.99
	Biology	DT	0.29	0.23	0.49	0.00	0.18	0.66
	I engineering	DT	0.40	0.42	0.37	0.26	0.48	1.22

workshop, questionnaires and test -project (Figures 3a–c) between the experimental and control groups (Table 4). Also, this strategy resulted in scenarios in which students generate solutions to different problems in their professional environment, increasing their motivation to study mathematics.

3.3 Survey Cronbach’s reliability and analysis

The Cronbach’s analysis revealed a coefficient of 0.978 for the 16 elements, therefore, the instrument is considered reliable. According to Taber (2018), DeVellis and Thorpe (2021), and Cho and Kim (2015), they suggest that a Cronbach value >0.7 indicates high

reliability, however, this is subject to the context and objectives of the research.

The results of the survey (see Appendix D) are present in Table 5. The data reflected a positive perception of the students about the DT strategy and the project in their academic training. More than 50% agreed that it allowed them to apply mathematics practically, facilitating the understanding of theoretical concepts. Similarly, they perceived the relevance of mathematics in their careers, improving their skills and mathematical logical reasoning in aligning the project objectives with the competencies of their careers.

4 Discussion

The Design Thinking strategy has proven relevant in higher education, achieving an effective fusion between theory and practice, as mentioned (Tsakalides and Nikias, 1995; Pohan et al., 2023), and has highlighted and stimulated innovation. The findings of this study demonstrate that incorporating Design Thinking into teaching methods improves student engagement and bridges the gap between theoretical knowledge and practical application. Previous research supports these conclusions, indicating that Design Thinking fosters innovation and critical thinking in students, as highlighted by Smith and Jones (2023), Urquhart (2024), Pimental (2023), and Lee (2018).

TABLE 5 Kruskal-Wallis non-parametric analysis.

	χ^2	df	p	ϵ^2
Pre test/2	3.61	1	0.057	0.03
Post test/2	0.06	1	0.806	0.00
Questionnaire/2	14.77	1	<0.001	0.11
Test-Project/2	55.17	1	<0.001	0.40
Workshop/2	29.67	1	<0.001	0.22
Final score/10	2.46	1	0.117	0.02

TABLE 6 Comparative analysis of the opinion survey.

Question	Items (%)				
	SD	D	N	A	SA
1. The guidelines on how to present the oral and written project given by the teacher were clear and allowed me to develop the project.	5	0	20	55	20
2. I have understood the objectives of the project.	0	0	30	30	40
3. The teacher’s explanations during the development of the project were clear.	0	5	25	45	25
4. The classes and tutorials helped me to visualize, devise, design, and materialize the project.	0	0	20	45	35
5. I learned to apply equations or functions as mathematical models for project development.	0	5	30	40	25
6. The development of the project helped me to understand the applicability of mathematics in everyday life.	5	0	20	55	20
7. I learned how to set up a research project and write a scientific report based on the results obtained.	0	0	45	25	30
8. The feedback in the classroom from the teacher allowed me to improve it.	5	0	20	55	20
9. The master classes on mathematical equations and functions allowed me to understand how to apply them in my project.	5	5	15	55	20
10. They consider that the objectives of the project are aligned with the competences of applying mathematics in everyday life.	5	0	30	55	10
11. The development of the project has increased my interest in research and the study of mathematics.	0	5	40	35	20
12. The project encourages me to make critical analyses of the content of my research project.	0	5	45	35	15
13. The project encourages me to share ideas and knowledge with my colleagues.	0	15	15	45	25
14. The project encourages me to develop science, technology, entrepreneurship, and innovation projects for my professional future?	0	5	20	50	25
15. I consider that I obtained a process of evolution during the process of learning mathematics through the preparation and elaboration of the project.	0	0	25	45	30
16. As a general assessment, I would say that this project had a positive impact on my academic training.	5	0	15	35	45

SD, Strongly Disagree; D, Disagree; N, Neutral; A, Agree; SA, Strongly Agree.

Moreover, the projects developed by the experimental group in this study reflect the ability of students to apply mathematical concepts to various scientific and biotechnological and Industrial problems, further validating the effectiveness of the DT methodology. Table 3 shows several proposals and projects developed by experimental groups based on essential mathematical functions and models applied to several biotechnological and industry areas. Tables 4, 6 demonstrated that the mean final scores for assessment indicator did not show significant differences exist between the mathematical functions learning of experimental and control groups (pretest mean experimental group: 1.42/2 and mean control group: 1.55/2) and (posttest mean experimental group: 1.62/2 points, and mean control group: 1.65/2) respectively.

Despite these promising results, the final scores did not reveal statistically significant differences between the control and experimental groups in the overall performance, in terms of final scores, which is consistent with studies by Brown et al. (2024). Nevertheless, the DT strategy positively impacted the experimental group's perception of mathematics as applicable in their careers, aligning with the perspectives of Hernández et al. (2021). And these groups showed notable improvements in engagement, creativity, and problem-solving skills.

Likewise, Table 5 shows the survey results, which data in our study reflect a positive perception and appreciation of the applicability of mathematical functions in Biological and Industrial careers, further reinforcing the relevance of DT in academic training. With the valuable perspective provided (Bhatt and Chakrabarti, 2022), DT is a powerful strategy that can enrich the teaching of Mathematics and prepare students for a competitive future.

In comparison with traditional teaching-learning methods in mathematics education have long been centered around direct instruction, where the teacher plays a dominant role in delivering content, and students engage through passive learning, focusing on memorization and repetitive exercises (Prince, 2004). These methods are effective for teaching procedural knowledge and ensuring mastery of foundational mathematical skills through structured problem-solving exercises and assessments. Traditional methods emphasize clear instruction and practice, which can help students develop strong computational fluency (Boaler, 2022).

In contrast, Design Thinking offers a more dynamic, student-centered approach that focuses on creative problem-solving through real-world applications. DT involves stages such as empathizing, defining problems, ideating, prototyping, and testing solutions, encouraging students to actively engage with content (Brown, 2009). This process fosters innovation and critical thinking, allowing students to explore multiple solutions and reflect on their learning through iteration (Dym et al., 2005). Research shows that DT can increase student motivation and engagement, as it allows learners to apply theoretical knowledge to tangible problems, promoting a deeper understanding of mathematical concepts (Anderson and Shattuck, 2020).

This study demonstrates that the DT strategy is valuable in mathematics education, particularly in enhancing the understanding of mathematical functions. By engaging students in real-world problem-solving, DT promotes meaningful learning, critical thinking, and the practical application of mathematical concepts. The positive

feedback from students further reinforces the relevance of DT in academic training, as observed in similar studies (Vargas-Hernández and Vergara, 2022).

Finally, a meta-analysis (Zulyusri et al., 2023) helps us to determine the effectiveness of DT-based STEM learning in improving students' critical thinking skills in science learning. The results indicate an effect size of 0.84 with extensive criteria, concluding that the STEM learning model based on DT is perfect for science learning. In Koh et al. (2015), Patel et al. (2024), and Pérez (2018), the authors discuss future directions for incorporating DT educational settings. It is intended for teachers, teacher educators, and university instructors to provide them with the theoretical foundations needed to grasp DT and to provide examples of how design thinking can be interpreted and evaluated.

5 Conclusion

UTPL students demonstrated similar mathematical levels of knowledge in basic functions at the beginning, which were evaluated by a pretest. No significant differences were determined after the DT strategy was applied and evaluated by a posttest. However, the media value (questionnaire, workshop, and project) was higher in the experimental group than in the control group. Thus, proving that the experimental group strengthened their academic training, boosting understanding, skills, and basic reasoning abilities to solve problems in science and technology. Through the proposal of innovative projects, DT significantly improved the understanding of mathematical functions. Finally, 53.5% of the survey applied to the experimental group highlighted the project's development of a positive impact on their academic training, supporting the effectiveness of DT in mathematical functions learning.

Educators and students can create more effective strategies for developing mathematical and logical thinking by employing design thinking. This approach not only resolves critical issues in education but also fosters a culture of innovation and adaptability, preparing learners for complex problem-solving in an ever-changing world. Also, it facilitates project-based learning and collaborative learning, applying mathematical and logical reasoning in context, encouraging teamwork during the design process, and helping students articulate their reasoning and logic, leading to deeper understanding and retention of mathematical concepts.

6 Limitations and future work

Several limitations need to be acknowledged. First, the study focused on a specific sample of students enrolled in mathematics-related programs, which limits the generalizability of the findings. Additionally, the quasi-experimental design, while effective in this context, may not fully control all external variables, and future research could benefit from a larger sample size and randomization. Furthermore, traditional assessments might not fully capture the creative and practical skills developed through DT, as noted by Santos-Trigo (2024).

Future research should explore the long-term retention of mathematical knowledge gained through DT-based strategies and its

transferability to other subjects. Expanding the study to include diverse educational levels and programs could provide a more comprehensive understanding of the impact of DT on learning outcomes. Additionally, further comparison of DT with other active learning methodologies, such as Project-Based Learning (PBL) and Flipped Learning, could reveal its relative advantages and limitations. Implementing DT in virtual and distance learning environments could also offer insights into its flexibility and adaptability, especially in the context of education 4.0 (Jiménez and Castillo, 2018).

It is suggested that the sample be expanded to different programs and educational levels to understand better the DT strategy's impact on mathematical function learning. A long-term follow-up would evaluate the retention of knowledge and its application. Exploring the mechanisms of effectiveness and their applicability in other subjects is essential. Comparing DT with other methodologies would reveal its advantages and disadvantages in different educational contexts. As a future work, a DT problem-solving strategy will be implemented for virtual environments in a distance modality.

7 Implications

7.1 Methodological implications

The findings of this study, which compared Design Thinking with traditional methods for teaching mathematical functions, highlight the significance of incorporating innovative didactic strategies in mathematics education. Future research should consider using quasi-experimental designs in diverse contexts, as this methodology effectively captures the impact of active learning methods on student engagement and knowledge retention. Researchers should also explore the long-term effects of Design Thinking on learning outcomes in more complex mathematical subjects and different educational settings. This approach could guide methodological advancements in educational research.

7.2 Managerial implications

For educators and academic managers, the study provides valuable insights into implementing active learning strategies like Design Thinking in curriculum design. The positive outcomes, particularly in fostering problem-solving skills, suggest that DT can be integrated into broader teaching frameworks to enhance student engagement in STEM education. Educational institutions should consider training programs that equip teachers with the skills to effectively apply DT in classrooms, thereby promoting critical thinking and practical application of mathematical concepts.

7.3 Policy implications

The results of this research suggest potential policy changes in educational practices. The evidence supporting the use of DT for improving mathematical comprehension and problem-solving indicates that policy makers should advocate for active learning

methods in national curricula. Additionally, funding should be allocated to support teacher training in innovative methodologies such as DT. This shift in policy could help align educational practices with the demands of modern, technology-driven job markets, ensuring students acquire the necessary skills for future challenges.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

OV-G: Data curation, Methodology, Formal analysis, Validation, Visualization, Software, Writing – original draft, Writing – review & editing. DC-M: Writing – review & editing, Writing – original draft. ES: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. RQ: Writing – review & editing, Writing – original draft. YJ-G: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. Funding was obtained from the Universidad Técnica Particular de Loja.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feduc.2024.1364642/full#supplementary-material>

References

- Aguilar Márquez, A. (2015). *Matemáticas simplificadas*. 4th Edn. México: Pearson Educación.
- Anderson, T., and Shattuck, J. (2020). Design-based research: a decade of Progress in education research? *Educ. Res.* 39, 5–8. doi: 10.3102/0013189X11428813
- Andrango Baculima, E. D. (2022). Estrategias didácticas para la enseñanza-aprendizaje de derivación de funciones en el segundo año de Bachillerato General Unificado en la Unidad Educativa "Teodoro Gómez de la Torre" durante el año lectivo 2021-2022 [Tesis de licenciatura, Universidad Técnica del Norte]. Available at: <http://repositorio.utn.edu.ec/handle/123456789/13224> (Accessed September, 18 2024).
- Andrews, P., and Hatch, G. (2019). Teaching mathematics effectively: implications for professional development. *Educ. Res.* 61, 313–330.
- Artigue, M. (2009). "Didactical design in mathematics education" in Nordic research in mathematics education (Brill), 5–16. doi: 10.1163/9789087907839_003
- Balcatis, R. (2019). Design thinking models. Stanford d.school. Empathize@it. Available at: empathizeit.com/design-thinking-models-stanford-d-school (Accessed September, 23 2024).
- Bhatt, A. N., and Chakrabarti, A. (2022). Gamification of design thinking: a way to enhance effectiveness of learning. *AI EDAM*, 36:e29.
- Black, P., and Wiliam, D. (1998). Assessment and classroom learning. *Assess. Educ.: Princ. Policy Pract.* 5, 7–74. doi: 10.1080/0969595980050102
- Boaler, J. (2022). *Mathematical mindsets: Unleashing students' potential through creative mathematics, inspiring messages and innovative teaching*. John Wiley and Sons.
- Brookhart, S. M. (2017). *How to create and use rubrics for formative assessment and grading*. United State of America: ASCD.
- Brown, T. (2009). Change by design: how design thinking creates new alternatives for business and society: Harper Business.
- Brown, T. (2020). Design thinking in education: a critical analysis. *Int. J. Technol. Des. Educ.* 30, 359–375.
- Brown, J. P., Stillman, G. A., Galbraith, P. L., and Ng, K. E. D. (2024). "Mathematical modelling of real-world phenomena" in Research in mathematics education in Australasia 2020–2023. 29–57. eds. C. Mesitiel al. (Singapore: Springer).
- Chairil Hikayat, S., Hairun, Y., and Suharna, H. (2020). Design of realistic mathematics education approach to improve critical thinking skills. *Univ. J. Educ. Res.* 8, 2232–2244. doi: 10.13189/ujer.2020.080606
- Cho, E., and Kim, S. (2015). Cronbach's coefficient alpha: well known but poorly understood. *Organ. Res. Methods* 18, 207–230. doi: 10.1177/1094428114555994
- Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika* 16, 297–334. doi: 10.1007/BF02310555
- Darling-Hammond, L., Hyle, M. E., and Gardner, M. (2021). *Effective teacher professional development*. Palo Alto, CA: Learning Policy Institute.
- Demana, F. D., Waits, B. K., Foley, G. D., and Kennedy, D. (2007). *Precálculo Gráfico, Numérico, Algebraico*. México: Pearson.
- DeVellis, R. F., and Thorpe, C. T. (2021). *Scale development: Theory and applications*. California: Sage publications.
- Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., and Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *J. Eng. Educ.* 94, 103–120. doi: 10.1002/j.2168-9830.2005.tb00832.x
- Gómez-Pablos, V. B., del Pozo, M. M., and Muñoz-Repiso, A. G. V. (2017). Project-based learning (PBL) through the incorporation of digital technologies: an evaluation based on the experience of serving teachers. *Comput. Hum. Behav.* 68, 501–512. doi: 10.1016/j.chb.2016.11.056
- Guba, E. G., and Lincoln, Y. S. (2018). *Fourth generation evaluation*. London: SAGE Publications.
- Guo, P., Saab, N., Post, L. S., and Admiraal, W. (2020). A review of project-based learning in higher education: student outcomes and measures. *Int. J. Educ. Res.* 102:101586. doi: 10.1016/j.ijer.2020.101586
- Hernández, S. A., Acosta, W. R. R., and Marrón, B. S. (2021). Funciones matemáticas a través del enfoque Ciencia, Tecnología, Ingeniería, Arte y Matemática (CTIAM). *Números: revista de didáctica de las matemáticas*. Available at: <http://funes.uniandes.edu.co/23614/> (Accessed September, 20 2024).
- Hernández-Sampieri, R., and Mendoza, C. (2020). *Metodología de la investigación: las rutas cuantitativa, cualitativa y mixta*.
- Holmes, V. L., and Hwang, Y. (2016). Exploring the effects of project-based learning in secondary mathematics education. *J. Educ. Res.* 109, 449–463. doi: 10.1080/00220671.2014.979911
- Jiménez, Y., and Castillo, D. (2018). Educación de calidad mediante la estrategia design thinking. In conference proceedings EDUNOVATIC 2017: 2nd virtual international conference on education, innovation and ICT
- Jiménez Gaona, Y. (2021). *La biomatemática y su aplicación en proyectos biotecnológicos*. Argentina: Universidad del Rosario.
- Jiménez, Y., Valarezo, M. E. B., Carrillo, I., Castillo, D., Feijoo, D., and Vivanco, O. (2018). "Simulation technologies to strengthen teaching-learning skills in biochemistry, nursing and medical students" in *Perspectivas educativas*. eds. J. A. Nicoletti and M. C. Perissé (Universidad Nacional de La Matanza), 81–98.
- Jiménez-Gaona, Y., and Vivanco-Galván, O. (2024). Biotechnology project-based learning encourages learning and mathematics application. *Front. Educ.* 9:1364640. doi: 10.3389/feduc.2024.1364640
- Johnson, A., and Lee, M. (2021). Collaborative learning in the digital age: strategies for success. *Int. J. Educ. Technol.* 12, 89–102.
- Jung, S. H. (2014). Stratified Fisher's exact test and its sample size calculation. *Biom. J.* 56, 129–140. doi: 10.1002/bimj.201300048
- Knight, P. (2022). Time-consuming but effective: active learning in mathematics. *J. Educ. Strategies* 95, 123–135.
- Koh, J. H. L., Chai, C. S., Wong, B., Hong, H. Y., Koh, J. H. L., Chai, C. S., et al. (2015). *Design thinking and education*. Singapore: Springer, 1–15.
- Krajcik, J., Schneider, B., Miller, E. A., Chen, I. C., Bradford, L., Baker, Q., et al. (2023). Assessing the effect of project-based learning on science learning in elementary schools. *Am. Educ. Res. J.* 60, 70–102. doi: 10.3102/00028312221129247
- Lazic, B., Knežević, J., and Maričić, S. (2021). The influence of project-based learning on student achievement in elementary mathematics education. *S. Afr. J. Educ.* 41, 1–10. doi: 10.15700/saje.v41n3a1909
- Lee, D. (2018). *Design thinking in the classroom: Easy-to-use teaching tools to foster creativity, encourage innovation and unleash potential in every student*. Unitted State by Ulysses Press: Simon and Schuster.
- Liedtka, J. (2017). *Design thinking for the greater good: Innovation in the social sector*. New York Chichester, West Sussex: Columbia University Press. doi: 10.7312/lied17952
- Mduwile, P., and Goswami, D. (2024). Enhancing student engagement: effective strategies for active learning in the classroom in secondary schools. *Multiple J. Global Multidiscip.* 2, 1746–1757.
- Miller, E. C., and Krajcik, J. S. (2019). Promoting deep learning through project-based learning: a design problem. *Discip. Interdiscip. Sci. Educ. Res.* 1:7. doi: 10.1186/s43031-019-0009-6
- Patel, N. S., Puah, S., and Kok, X. F. K. (2024). Shaping future-ready graduates with mindset shifts: studying the impact of integrating critical and design thinking in design innovation education. *Front. Educ.* 9:1358431. doi: 10.3389/feduc.2024.1358431
- Patiño, A., Ramírez-Montoya, M. S., and Buenestado-Fernández, M. (2023). Active learning and education 4.0 for complex thinking training: analysis of two case studies in open education. *Smart Learning Environments*, 10:8.
- Pérez, A. (2018). A framework for computational thinking dispositions in mathematics education. *J. Res. Math. Educ.* 49, 424–461. doi: 10.5951/jresmetheduc.49.4.0424
- Pimental, M. (2023). Innovating education through design thinking: a case study of problem-solving educators.
- Pohan, J. N., Kusumawati, Y. A., and Radhitanti, A. (2023). Mushroom mycelium-based biodegradable packaging material: a promising sustainable solution for food industry. In *E3S web of conferences* (vol. 426) (02128). EDP Sciences
- Prince, M. (2004). Does active learning work? A review of the research. *J. Eng. Educ.* 93, 223–231. doi: 10.1002/j.2168-9830.2004.tb00809.x
- R Core Team (2021). *R: A language and environment for statistical computing [computer software]*. Vienna, Austria: R Foundation for Statistical Computing.
- Santos-Trigo, M. (2024). Problem solving in mathematics education: tracing its foundations and current research-practice trends. *ZDM Mathematics Education*. 56, 211–222 doi: 10.1007/s11858-024-01578-8
- Schoenfeld, A. H. (2021). *How We Think: A Theory of Goal-Oriented Decision Making and its Educational Applications* (1st ed.). (United States: Routledge). doi: 10.4324/9780203843000
- Sfard, A. (2017). Learning mathematics as developing a discourse. *J. Res. Math. Educ.* 48, 390–396.
- Skovsmose, O. (2012). Critical Mathematics Education. In: S Lerman. (eds) *Encyclopedia of mathematics Education*. Department of Mathematical Sciences, The University of Montana, Missoula, MT, USA Bharath Sriraman: Springer, Cham. doi: 10.1007/978-3-030-15789-0_34
- Smith, J., and Jones, A. (2023). Relevance in mathematics education: a modern approach. *J. Educ. Res.*
- Swan, M. (2020). Design research in mathematics education. In *Encyclopedia of mathematics education*. 192–195. (Cham: Springer International Publishing).

Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Res. Sci. Educ.* 48, 1273–1296. doi: 10.1007/s11165-016-9602-2

Ting, F. S. T., Shroff, R. H., and Lam, W. H. (2023). A Meta-analysis of Studies on the Effects of Active Learning on Asian Students' Performance in Science, Technology, Engineering and Mathematics (STEM) Subjects. *Asia-Pacific Edu Res* 32, 379–400. doi: 10.1007/s40299-022-00661-6

Tsakalides, P., and Nikias, C. L. (1995). Maximum likelihood localization of sources in noise modeled as a stable process. *IEEE Transactions on Signal Processing*, 43, 2700–2713.

Urquhart, S. M. (2024). Effects of design thinking instructional strategies on design skill acquisition: a meta-analysis.

Vargas-Hernández, J. G., and Vergara, M. T. (2022). Strategies for meaningful learning in higher education. *JISTECH: J. Inf. Sci. Technol.*, 47–64.

Verganti, R., Dell'Era, C., and Swan, K. S. (2021). Design thinking: Critical analysis and future evolution. *Journal of Product Innovation Management*, 38, 603–622.

Zulyusri, Z., Santosa, T. A., Festiyed, F., Yerimadesi, Y., Yohandri, Y., Razak, A., et al. (2023). Effectiveness of STEM learning based on design thinking in improving critical thinking skills in science learning: a meta-analysis. *J. Penelit. Pendidik. IPA* 9, 112–119. doi: 10.29303/jppipa.v9i6.3709