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Regular Article

Culturally responsive challenge-based STEM education: A pre–post study with rural and Indigenous primary students in Mexico

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ABSTRACT

High-quality Science, Technology, Engineering, and Mathematics (STEM) education is widely recognized as a catalyst for sustainable development because it cultivates critical thinking, creativity, and digital literacy. Mexico's Ministry of Public Education echoes this view through national STEAM initiatives that call for culturally relevant strategies capable of reaching historically marginalized rural and Indigenous communities. Challenge-Based Learning (CBL) and STEAM activities, such as building edible DNA models, culinary algorithms and zero-kilometer food challenges, offer a promising remedy: they merge core scientific concepts with hands-on, arts-infused tasks that rely on inexpensive, locally sourced materials.

To examine their potential association with changes in students′ perceptions, this study adopted a quasi-experimental pre-test/post-test design without a control group. A total of 230 sixth-grade primary school students from two remote regions completed a validated questionnaire before and after five contextualized STEM challenges. Descriptive statistics, paired samples tests, and subgroup analyses explored gender and geography-based differences. Students' overall perceptions of STEM improved significantly ($p < 0.01$), with the largest gains in Technology and Mathematics. However, shifts in career aspirations and self-efficacy were not statistically significant, and gender- or region-based differences proved negligible.

These results suggest that short CBL interventions may be associated with improvements attitudes but may be insufficient to influence vocational outcomes. Policymakers and practitioners working in low-resource settings can leverage CBL to make STEM learning more engaging. Extending program duration, embedding culturally contextualized materials, and integrating explicit career guidance could magnify impact and help advance Sustainable Development Goals 4 and 10.

1. Introduction

High-quality Science, Technology, Engineering and Mathematics (STEM) education is increasingly recognized worldwide as a cornerstone of sustainable development. Governments and international organizations emphasize that STEM education equips young people with critical thinking, creativity, problem-solving skills, and digital literacy required in rapidly changing labor markets. Building on this global consensus, STEM education has become a central focus in international research and educational initiatives aimed at developing competencies for the 21st century (Castro-Campos, 2023; Duo-Terron et al., 2022; Fernández & Romero, 2020; Inostroza et al., 2020; Vicente et al., 2021).

Aligned with this commitment, however, developing competencies such as critical thinking, creativity, and problem-solving cannot rely on digital tools alone. Equitable STEM learning also depends on unplugged activities that nurture computational thinking (Chen et al., 2023; Sigayret et al., 2022; Zhang et al., 2025).

By intentionally integrating the arts, the STEAM approach broadens traditional STEM and amplifies its educational impact (Conradty & Bogner, 2020). When STEM challenges integrate scientific and

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mathematical concepts into real-world tasks, they can enhance students' motivation, creativity, and engagement with STEM disciplines through hands-on learning experiences (English & King, 2015, 2019; Nadelson & Seifert, 2019; Rennie et al., 2018; Shealer & Shealer, 2014; Tytler et al., 2021).

However, these learning experiences face challenges in vulnerable communities, particularly in rural and Indigenous areas, where significant gaps persist in students' participation in STEM activities. A lack of adequate resources can disrupt the learning process and negatively affect students' STEM identity, rendering their ways of thinking and acting invisible (Fonseca-Factos & Simbaña-Gallardo, 2022; Olivar-Molina & Flores-López, 2024).

It is therefore essential to develop strategies that connect STEM education with Indigenous knowledge systems, fostering greater interest and engagement among Indigenous students (Quezada Carrasco, 2024; Silva et al., 2020). These efforts reflect growing international interest in promoting inclusive and equitable STEM education.

Educational inequalities in Mexico are especially pronounced due to historical, economic, and cultural factors limiting access to quality learning opportunities (UNESCO, 2021). In Latin America, STEM education is still in its early stages and remains relatively unknown among early childhood and primary school educators (Cabello et al., 2021; Yim et al., 2024). By contrast, in more developed countries, its implementation has advanced more rapidly to support students' future success (Ata-Aktürk & Demircan, 2017).

Incorporating STEAM activities into primary education has increased student motivation and engagement with STEM disciplines (Ortiz-Revilla et al., 2021). It also supports the development of future-ready skills (Das, 2021) and helps students understand, identify, and address real-world problems through STEAM challenges (Bass et al., 2016; Rodrigues-Silva & Alsina, 2023). Inclusive and intercultural STEM education promotes innovation and contributes to a more equitable society (Ramos-Navas-Parejo et al., 2020; Rojas et al., 2018). For this reason, promoting such activities in primary education is critical, as it is a formative stage for students' personal, social, and educational development (UNESCO, 2021).

García-Silva, García-Holgado, and Sánchez-Gómez (2024) emphasize the importance of creating initiatives that promote STEM education through practical activities. In this context, the Retos Indigenius: Inspiring Futures in STEM project was developed to address educational inequalities through a strategy based on solving practical, contextualized challenges. The project aims to positively impact elementary school students 'perceptions of STEM, with a focus on rural and semi-urban communities in *Nuevo León and Chiapas*, Mexico, where Indigenous student populations are significant (García-Silva, García-Holgado, García-Holgado et al., 2024).

The challenges implemented in Retos Indigenius: Inspiring Futures in STEM project were designed by female professors of Engineering and Architecture at the University of Salamanca in collaboration with professionals in the field, as part of the "Engineering with a Gender Perspective" initiative (35/7ACT/21) (González-Rogado et al., 2023). These challenges aim to demonstrate that Engineering, Architecture, Science, Mathematics, and Technology are present in many aspects of everyday life, from food to transportation. Moreover, they are designed to be accessible to children and youth with diverse abilities, promoting inclusive and gender-sensitive learning experiences.

Although the challenges were initially developed by faculty at the University of Salamanca, all activities implemented in the Retos Indigenius: Inspiring Futures in STEM project were adapted to the specific cultural and educational contexts in which they were carried out. These adaptations ensured that the challenges were culturally relevant and aligned with the students' experiences and prior knowledge.

Despite the growing body of research on STEM education, limited empirical evidence exists on culturally responsive Challenge-Based STEM interventions implemented in Indigenous primary education contexts using quasi-experimental pre–post designs. This gap limits understanding of how contextualized hands-on challenges influence early STEM engagement among historically underrepresented students.

The objective of this study is to examine the impact of a culturally responsive Challenge-Based STEAM intervention implemented in primary schools serving rural and semi-urban communities with significant Indigenous populations in *Cadereyta Jiménez, Nuevo León, and San Cristóbal de las Casas, Chiapas,* Mexico. Using a quasi-experimental pre–post design, the study evaluates changes in students' perceptions of STEM disciplines, as well as perceptions related to STEM careers, perceived ability, and expected success following participation in the intervention. The study also explores whether these outcomes vary according to students' gender and geographic region.

Accordingly, this study addresses the following research questions:

RQ1. Does participation in the culturally responsive Challenge-Based STEAM intervention lead to changes in students' perceptions of STEM disciplines?

RQ2. Does the intervention influence students' perceptions related to STEM careers, perceived ability, and expected success in STEM fields?

RQ3. Do changes in students' STEM perceptions differ according to gender or geographic region?

This study contributes empirical evidence on culturally responsive Challenge-Based STEAM interventions in Indigenous primary education contexts and advances understanding of early STEM engagement among historically underrepresented students.

2. Challenge-based learning

Challenge-Based Learning (CBL) is a multidisciplinary educational framework that places students at the center of their own learning. By engaging with authentic, real-world challenges, learners develop reflective, socially committed attitudes toward their communities (Nichols & Cator, 2008). CBL fosters collaboration across disciplines while cultivating core competencies such as evidence-based decision-making, clear communication, and strategic problem-solving (De La Cruz et al., 2022). Working on these challenges also boosts students' self-esteem, mathematical and logical reasoning, and creative thinking. Because it ties knowledge acquisition to hands-on applications, CBL prepares students for future careers. It nurtures both disciplinary and trans-disciplinary skills, shifts ownership of the learning process to the learners, and sustains motivation through active, inquiry-driven tasks (Gallagher & Savage, 2023). A hallmark of CBL is its use of global, real-world issues as catalysts for learning (Doulougeri et al., 2024).

These definitions converge on two key ideas: learning should begin with authentic challenges, and students should address them in active, collaborative, and multidisciplinary ways, ideally in international contexts, to create sustainable solutions (van den Beemt et al., 2023). Implementing CBL, therefore, requires robust support for teachers and tutors, both in designing meaningful challenges and in managing the uncertainties that inevitably arise during the process (Membrillo-Hernández & García-García, 2020).

CBL also aligns with culturally responsive pedagogy, which holds that effective instruction must honor students' languages, cultural histories, and epistemologies (Gay, 2018). In this study, culturally responsive principles were operationalized through the design of locally relevant STEM challenges and the adaptation of instructional materials to the sociocultural context of rural and Indigenous students. These challenges were intended to connect STEM learning with issues and experiences familiar to students' communities.

The integration of Indigenous and scientific knowledge has gained prominence across disciplines such as environmental management, agriculture, health care, and education (Ijatuyi et al., 2025). To adapt CBL to Indigenous Mexican contexts, iterative co-design with local teachers and community elders is essential. Such collaboration ensures that the selected challenges reflect community priorities, whether sustainable food systems, water practices, agroecology, or traditional architecture, and that they are addressed in culturally meaningful ways.

From a motivational perspective, Challenge-Based Learning can also be interpreted through established theories of student engagement. According to expectancy-value theory, students are more likely to engage in learning activities when they believe they can succeed and perceive the task as meaningful or valuable (Eccles & Wigfield, 2002). Similarly, self-efficacy theory suggests that students' beliefs about their ability to perform a task influence their motivation, persistence, and academic choices (Bandura et al., 2001). By involving learners in collaborative problem-solving and real-world challenges, CBL can strengthen both perceived competence and task value, which are key drivers of engagement in STEM learning.

Building on these theoretical perspectives, this study examines how a culturally contextualized Challenge-Based STEM intervention may influence students' perceptions of STEM disciplines, STEM careers, perceived ability, and expected success in STEM fields. The conceptual relationships guiding the intervention and its expected outcomes are summarized in Fig. 1.

3. Methodology

3.1. Research design

This study followed a quantitative approach and employed a quasi-experimental pre-test/post-test design without a control group to examine changes in students' perceptions of STEM after participating in a challenge-based STEAM intervention. This design was selected because, given the rural and Indigenous context, it was neither feasible nor ethical to exclude any students from the intervention. Participating schools requested that all students be included in the activities to ensure equal learning opportunities. Consequently, the study focused on examining potential changes in students' perceptions of STEM following their participation in the project.

3.2. Participants and context

Participants were selected through convenience sampling, based on schools that agreed to collaborate with the project and that served communities with a significant Indigenous student population. All sixth-grade students enrolled in the participating schools were invited to participate.

Initially, a total of 332 sixth-grade students participated in the project: 170 from *Cadereyta Jiménez, Nuevo León* (Region 1), and 162 from *San Cristóbal de las Casas, Chiapas* (Region 2). However, due to incomplete responses in either the pre-test/post-test, the final analyzed sample was reduced to 230 students (111 males and 119 females). This adjustment ensured internal validity when comparing results before and after the intervention. The main inclusion criteria were institutional approval and the provision of informed consent by parents or legal guardians. Table 1 presents the final distribution of participants by gender and region. Excluded cases corresponded to incomplete questionnaires; therefore, no additional demographic comparison between included and excluded participants was possible.

3.3. Description of the instrument

Data were collected through a questionnaire based on instruments previously validated in STEM education research. Specifically, it was adapted from the European CreaSTEAM project (Ref. 2020-1-ES01-KA201-082601) (Amo et al., 2021; Verdugo-Castro & García-Holgado, 2023). The instrument was culturally adapted to the context of rural and Indigenous communities in Retos Indigenius: Inspiring Futures in STEM project. The adaptation process involved reviewing wording to ensure age-appropriate language for primary school students and contextual relevance to the participating schools. Minor linguistic adjustments were made while preserving the conceptual structure of the original instruments. The adapted questionnaire was reviewed by members of the research team with experience in STEM education and culturally responsive educational interventions.

Table 1
Final distribution of the sample by gender and region.

Region	Initially convened	Excluded (Incomplete Pre- or Post-Test)	Analyzed Sample (Final)	Man	Women
Region 1	170	60	110	54	56
Region 2	162	42	120	57	63
Total	**332**	**102**	**230**	**110**	**120**

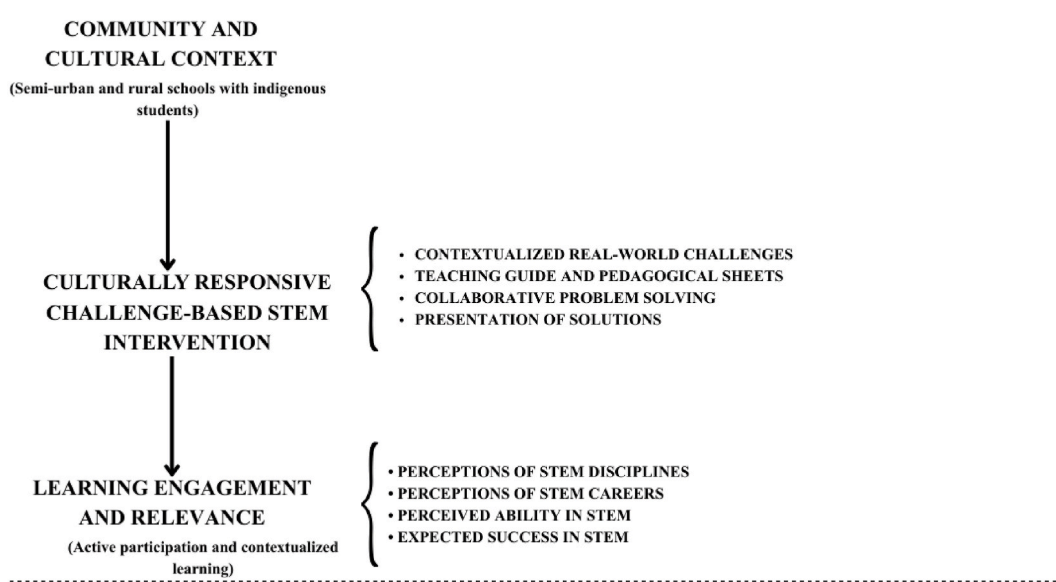

Fig. 1. Conceptual framework of the culturally contextualized Challenge-Based STEM intervention.
Source: Authors' own elaboration

The questionnaire was administered at two points: before (pre-test) and after (post-test) the intervention. It consisted of three sections:

1. Perception and motivation toward STEM: This section was assessed using the STEM Semantic Survey (Tyler-Wood et al., 2010), where students rated Science, Mathematics, Engineering, and Technology using pairs of contrasting adjectives (e.g., fascinating–mundane, exciting–unexciting, attractive–unattractive). This instrument has been widely used in STEM education research and has demonstrated strong internal consistency reliability, with reported Cronbach's alpha values ranging from $\alpha = 0.84$ to $\alpha = 0.93$.
2. Attitudes and confidence in STEM skills: This section was measured using a **5-point Likert scale** (1 = Strongly disagree; 5 = Strongly agree) adapted from the *Student Attitudes Toward STEM Survey for Middle and High School Students* (Faber et al., 2013). Eight items were selected: four related to motivation to pursue STEM careers and four related to students' perceived ability and expected success in STEM fields. This reduced set of items ensured participant engagement while maintaining the instrument's conceptual validity. The original instrument reported strong internal consistency, with Cronbach's alpha coefficients above 0.80 for the engineering attitudes scale and above 0.85 for the mathematics and science scales.
3. Satisfaction and qualitative feedback (post-test only): Students answered three open-ended questions: (1) What did you like the most? (2) What didn't you like? and (3) What would you change about the activity?

The questionnaires were administered in classroom settings by members of the research team with the support of classroom teachers. The surveys were completed under supervision to ensure students understood the instructions and responded independently. The pre-test was administered immediately before the intervention activities, and the post-test was completed after the challenges and reflection session.

3.4. Design of the challenge-based STEM intervention

3.4.1. Culturally responsive design

The design of the intervention followed principles of culturally responsive pedagogy, aiming to connect STEM learning with students' everyday experiences and community contexts. Rather than presenting STEM concepts as abstract content, the challenges incorporated familiar themes such as food systems, local materials, and community practices. During the activities, explanations and examples were intentionally linked to elements present in students' own communities in order to make the concepts more meaningful and accessible. This approach sought to relate scientific ideas to students' prior knowledge and local realities.

In addition, linguistic diversity among students was considered during the design and implementation of the activities. Given that some students speak Indigenous languages, teachers were available to support explanations when needed to facilitate comprehension and participation. This consideration aimed to ensure that the activities remained accessible to students with different linguistic backgrounds.

3.4.2. Structure of the intervention

The intervention was implemented during short, intensive STEM activity sessions integrated into the regular school schedule. Each challenge session lasted approximately 60-90 min, and students participated in two or three challenges per school visit, depending on the implementation phase. Each challenge was implemented in small collaborative groups of 5-6 students, promoting discussion, problem-solving, and hands-on experimentation.

3.4.3. Teacher support

To support classroom implementation, the didactic guides associated with the challenges were used. These guides included practical information such as the recommended educational level, required materials, learning objectives, transversal competences, and links to supporting resources.

During the implementation, the principal investigator used these guides as a pedagogical reference while adapting the activities to the local context. In particular, the facilitation of the sessions incorporated community values and local knowledge, following the culturally contextualized approach described in the previous section.

Although teachers did not receive formal training prior to implementation, the research team coordinated the activities and provided guidance during the sessions to maintain a coherent pedagogical structure across the challenges.

3.4.4. Implementation procedure

The implementation was divided into two phases during the 2024 academic year.

- **Phase 1**: Conducted on February 6 and 9, 2024, at *Edgardo Reyes Salcido*, Elementary School (*Cadereyta Jiménez, Nuevo León*) with 170 students. Students participated in three daily sessions (9:00-12:00, 12:00-14:00, 15:00-18:00) to solve the challenges "Edible DNA" and "Toothpick and Jelly Bean Lattices".
- **Phase 2**: Conducted from September 3 to 10, 2024 (9:00-13:30) in three elementary schools in *San Cristóbal de las Casas, Chiapas*. Each school completed three challenges: "Secret Messages with a Cypher Disk", "Culinary Algorithms", and "Zero-Mile Food".

All activities followed a standardized structure:

1. Introduction to the Retos Indigenius: Inspiring Futures in STEM project
2. Pre-test questionnaire administration
3. Explanation of key STEM concepts
4. Team formation and challenge execution
5. Presentation of solutions
6. Reflection and post-test administration

3.4.5. STEM challenge activities

Five hands-on challenges were implemented as part of the intervention. These activities were developed under the "All We Are STEAM-Retos WE" pedagogical framework (González-Rogado et al., 2024) and adapted to the cultural and material context of the participating communities.

Materials varied slightly between regions. In *Cadereyta Jiménez, Nuevo León*, students used project-provided kits including gummy candies, toothpicks, markers, and paper. In *San Cristóbal de las Casas, Chiapas*, students used recyclable materials such as cardboard and food packaging, which also promoted sustainability. This approach ensured that the activities relied on low-cost and accessible materials, facilitating their replication in low-resource educational contexts. Table 2 summarizes the STEM focus, description, and materials used in each challenge.

3.5. Data analysis

The questionnaire was administered in paper format during classroom sessions. After data collection, responses were manually entered into a spreadsheet and prepared for analysis. Statistical analyses were conducted using JASP (version 19.2) and IBM SPSS Statistics (version 28).

To ensure paired observations, only participants who completed both the pre-test and post-test were included in the analysis ($n = 230$). Cases with incomplete responses were excluded during data preparation, resulting in a final dataset with no missing values. Because incomplete cases were removed during this process, individual-level information for excluded participants was not retained, and therefore, a comparison between included and excluded students could not be

Table 2
Overview of STEM challenges, educational focus, materials, and learning activities.

Challenges	STEM Focus	Materials	Description	Link
Toothpick and Jelly Bean Lattices	Structural engineering	Toothpicks, gummy candies	Students built lattice frameworks with gummy candies + toothpicks provided by the team, modelling local bridges and traditional roof trusses.	https://youtu.be/ytiYK3a9KdU
Edible DNA	Molecular biology	Colored gummy candies, toothpicks	Students built double-helix models with colour-coded gummy candies and toothpicks supplied by the team	-
Zero-Mile Food	Sustainability and food origin	Recycled cardboard, markers, food packaging	Students mapped the origins of the foods they regularly consume, using recycled cardboard to illustrate supply routes and mark items that are qualified as *km-zero* (≤10 km)	https://youtu.be/ioA6q12X37k
Secret Messages with a Cypher Disk	Cryptography and logic	Cardboard, markers, fasteners	Students fabricated the cipher disk from recycled cardboard and hand-wrote alphabets before encoding and decoding community-based phrases.	https://youtu.be/cANEYEA1-To
Culinary Algorithms	Procedural/ algorithmic thinking	Recipe cards, paper, markers	Students translated traditional recipes into step-by-step instructions, illustrating the concept of algorithms through everyday cooking processes.	https://youtu.be/BIJVdrh887I

Note: A comprehensive teaching guide containing the full methodological instructions for all challenges was developed to support classroom implementation. Available at: https://zenodo.org/records/12544526.

performed.

In the original version of the questionnaire's first section, most items were coded such that low values (1) indicated positive perceptions and high values (5) indicated negative perceptions, except for the pairs "means nothing–means a lot (MN–ML)" and "boring–interesting (BOR–INT)," which were already reverse-coded.

To ensure consistency in statistical analysis and interpretation, the items "mundane–fascinating (MUND–FASC)," "not exciting–exciting (UNEXCIT–EXCIT)," and "unappealing–appealing (UNAPP–APP)" were also reverse-coded so that a score of 5 consistently represented the most positive perception, and a score of 1, the most negative.

Following data entry, pre-test and post-test responses were analyzed. Normality assumptions were examined using the Kolmogorov–Smirnov test. Results indicated significant deviations from normality ($p < 0.05$); therefore, non-parametric tests were applied. Specifically, the Wilcoxon signed-rank test was used to assess differences between pre-test and post-test scores, and the Mann–Whitney U test was used to compare independent groups based on gender and region. Effect sizes and 95% confidence intervals were also calculated to estimate the magnitude and precision of the observed differences.

4. Results

This section presents the findings from evaluating the Retos Indigenius: Inspiring Futures in STEM project, focusing on pre-test and post-test analyses. Descriptive statistics and hypothesis testing were used to identify differences in students' perceptions toward STEM fields. Additionally, analyses were conducted by gender and region.

4.1. Descriptive statistical analysis

The descriptive analysis provides an overview of trends in students' perceptions of STEM disciplines, comparing pre-test and post-test results. Data were collected through a structured questionnaire using a semantic differential scale, in which participants rated Science, Mathematics, Engineering, Technology, and overall STEM using pairs of opposing adjectives (Table 3).

The analysis showed a general increase in mean scores across all semantic dimensions following the intervention. Notably, students perceived STEM disciplines as more fascinating, with particularly significant gains in the Technology domain, where the mean score increased from (M = 2.02, SD = 1.29, CV = 0.64) to significantly

Table 3
Descriptive statistics for pre-test and post-test by STEM area.

AREAS STEM	ADJECTIVES	PRE-TEST			POST-TEST		
		Mean (M)	Std. Deviation (DE)	Coefficient of variation (CV)	Mean (M)	Std. Deviation(D)	Coefficient of variation (CV)
SCIENCE	MUND-FASC	4.03	1.27	0.32	4.37	0.96	0.22
	UNATTR-ATTR	3.90	1.27	0.33	4.32	0.91	0.21
	UNEXCIT-EXCIT	3.98	1.23	0.31	4.3	0.97	0.23
	MN-ML	4.04	1.19	0.29	4.51	0.89	0.2
	BOR-INT	4.21	1.16	0.28	4.55	0.86	0.19
MATH	BOR-INT	3.84	1.27	0.33	4.5	0.9	0.2
	UNATTR-ATTR	3.88	1.34	0.34	4.22	1.03	0.24
	MUND-FASC	3.78	1.28	0.34	4.21	1.12	0.27
	UNEXCIT-EXCIT	3.78	1.28	0.34	4.2	1.07	0.26
	MN-ML	3.96	1.31	0.33	4.52	0.82	0.18
ENGINEERING	UNATTR-ATT	3.84	1.2	0.31	4.21	0.97	0.23
	MUND-FASC	3.88	1.19	0.31	4.25	1.03	0.24
	MN-ML	3.97	1.21	0.3	4.47	0.84	0.19
	UNEXCIT-EXCIT	3.85	1.17	0.3	4.15	1.06	0.26
	BOR-INT	3.94	1.26	0.32	4.54	0.85	0.19
TECHNOLOGY	UNATTR-ATT	3.98	1.23	0.31	4.34	0.85	0.2
	MN-ML	4.08	1.17	0.29	4.54	0.75	0.16
	BOR-INT	4.01	1.17	0.29	4.6	0.7	0.15
	UNEXCIT-EXCIT	3.98	1.29	0.32	4.26	0.95	0.22
	MUND-FASC	2.02	1.29	0.64	4.37	0.99	0.23
STEM	MN-ML	4.13	1.12	0.27	4.5	0.82	0.18
	BOR-INT	4.14	1.1	0.27	4.55	0.78	0.17
	UNEXCIT-EXCIT	4,00	1.15	0.29	4.34	0.92	0.21
	MUND-FASC	4.07	1.25	0.31	4.42	0.93	0.21
	UNATTR-ATT	3.99	1.16	0.29	4.3	0.94	0.22

positive in the post-test (M = 4.37, SD = 0.99, CV = 0.23).

The semantic pair means nothing–means a lot *(MN–ML)* also showed notable improvement, especially in Mathematics (M = 3.96 to 4.52) and Engineering (M = 3.97 to 4.47). Overall, all pairs (MUND–FASC, UNATTR–ATTR, UNEXCIT–EXCIT, BOR–INT) reflected more positive post-test perceptions, alongside a reduction in coefficients of variation, indicating increased consensus and more favorable attitudes toward STEM after completing the project challenges (Fig. 2).

To complement the analysis, Table 4 presents pre-test and post-test descriptive statistics related to career aspirations, self-perceived abilities, and expectations of success in STEM.

Cronbach's alpha for the perceptions of disciplines dimension was 0.814 on the pre-test (95% CI: 0.763–0.865), indicating good internal consistency. The alpha increased to 0.863 on the post-test (95% CI: 0.828–0.899), reflecting improved scale reliability. The reduction in the standard error (from 0.026 to 0.018) also indicates more stable and accurate responses after the intervention.

The results suggest that students reported more positive perceptions of STEM disciplines after the intervention. Post-test mean scores increased relative to pre-test scores, particularly for career interest in Mathematics (from 3.69 to 3.76), Technology (from 3.83 to 3.87), and Engineering (from 3.41 to 3.55), as visualized in Fig. 3.

Moderate improvements were also observed in perceived abilities in Mathematics (from 3.30 to 3.42) and Science (from 3.60 to 3.65). Confidence in success within STEM careers showed slight increases in Engineering (from 3.42 to 3.55) and Technology (from 3.69 to 3.84). These shifts were accompanied by decreased standard deviations and coefficients of variation, suggesting a more consistent and homogeneous perception after the intervention.

4.2. *Pre-test-post-test analysis using the Wilcoxon test*

To assess the impact of the Retos Indigenius: Inspiring Futures in STEM project on students' perceptions toward STEM, inferential analysis was conducted using the Wilcoxon signed-rank test for related samples. This non-parametric method was chosen due to the non-normal distribution of the data and the need to compare pre-test and post-test results (Table 5).

The results indicate statistically significant differences in students' perceptions toward STEM disciplines after participating in the project ($p < 0.001$). The negative Z-values indicate higher post-test scores, confirming overall improvement. Effect sizes, reported as biserial correlation (ES), ranged from moderate to large, with the most potent effects in Technology (ES = −0.898) and Mathematics (ES = −0.737), followed by Engineering (ES = −0.610), overall STEM (ES = −0.594), and Science (ES = −0.555).

4.3. *Wilcoxon analysis: career choice, ability, and success perception*

This subsection examines whether the Retos Indigenius: Inspiring Futures in STEM intervention influenced students' perceptions of future career choices, self-assessed abilities, and expectations of success in STEM disciplines. These variables represent deeper motivational and identity-related aspects of STEM engagement, which are often more resistant to change than general attitudes. The Wilcoxon signed-rank test compared pre-test and post-test responses across these dimensions. The results are presented in Table 6.

The Wilcoxon test results show that Retos Indigenius: Inspiring Futures in STEM intervention did not significantly change students' perceptions of career choice, skills, or expectations of success ($p > 0.05$). While some dimensions, such as perceived math ability ($p = 0.069$, ES = −0.199) and interest in engineering careers ($p = 0.078$, ES = −0.179), showed trends toward improvement, these changes did not reach statistical significance, and the effect sizes were small.

Similarly, the results indicated success in Engineering ($p = 0.088$, ES = −0.182) and Technology ($p = 0.084$, ES = −0.179), with minor, non-significant improvements. These results contrast with the significant gains observed in general STEM perceptions (see Table 5), suggesting that while the intervention positively influenced students' attitudes and motivation, it did not substantially alter their confidence or vocational interest potentially due to the short duration of the program or external influencing factors.

4.4. *Comparative analysis by gender and region using non-parametric tests*

To further assess the impact of the Retos Indigenius: Inspiring Futures in STEM project, a comparative analysis was conducted considering two independent variables: gender and region. These factors are essential to understanding potential differences in students' perceptions toward STEM, helping to identify patterns related to participants' sociocultural backgrounds.

Because the data were collected at two points in time (pre-test and post-test) and across independent groups, appropriate statistical tests were applied. The Mann–Whitney *U* test was used to compare differences between independent samples (e.g., gender (Table 7) and region (Table 9). These analyses provide insights into whether the program's impact varied based on participant characteristics, offering guidance for future intervention adaptations.

The Mann–Whitney *U* test results indicate no statistically significant differences between male and female students across the evaluated STEM domains ($p > 0.05$). Effect sizes (ES) were also small, suggesting that the observed differences were minimal and insignificant. These

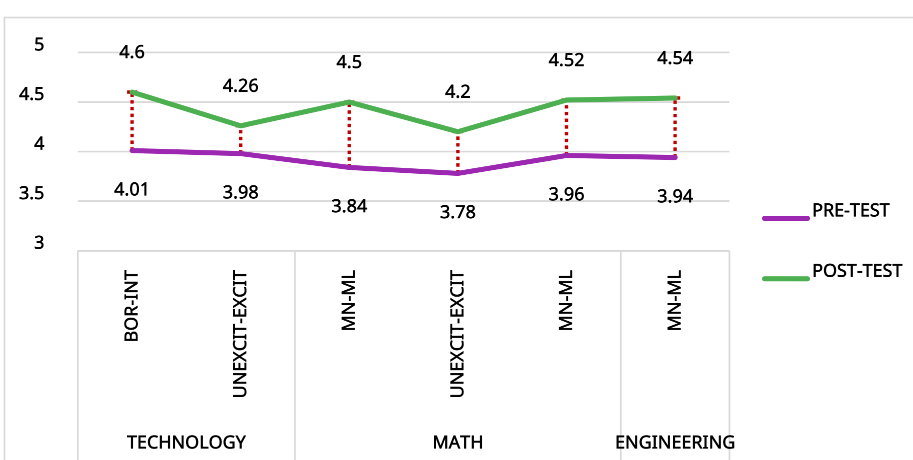

Fig. 2. Comparison of semantic pair ratings: Pre-test vs. Post-test.

Table 4
Descriptive statistics for pre-test and post-test: perceptions of disciplines.

	PRE-TEST				POST-TEST		
Perception of disciplines	N	Means (M)	Std. Deviation (DE)	Coefficient of variation (CV)	Media(M)	Desv. Estándar (DE)	Coefficient of variation (CV)
Math career	230	3.70	1.22	0.33	3.76	1.13	0.30
Science career	230	3.76	1.13	0.31	3.66	1.15	0.28
Technology career	230	3.84	1.14	0.30	3.87	1.09	0.28
Engineering career	230	3.42	1.19	0.35	3.58	1.13	0.31
Math ability	230	3.30	1.16	0.35	3.42	1.09	0.33
Science ability	230	3.60	1.02	0.28	3.65	1.04	0.29
Engineering success	230	3.42	1.15	0.34	3.55	1.13	0.32
Technology success	230	3.69	1.17	0.32	3.84	1.08	0,28

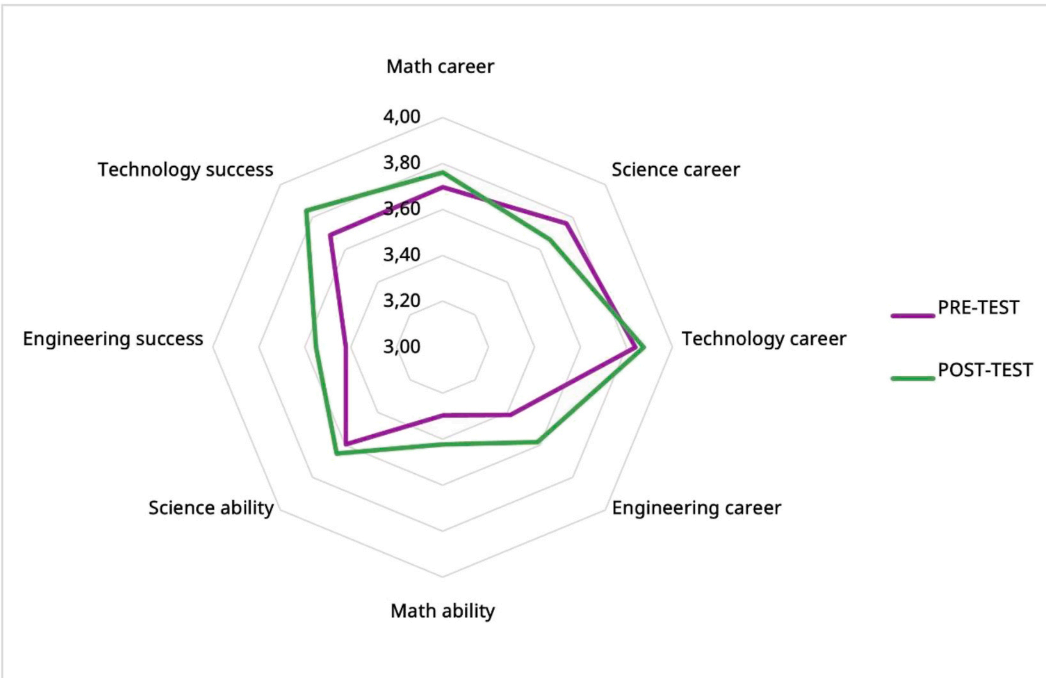

Fig. 3. Changes in STEM Perceptions: Pre-Test vs. Post-Test.

Table 5
Wilcoxon signed-rank test for perception toward STEM.

PRE-TEST VS. POST-TEST	W	Z	P	ES	95% CI	
					Lower	Upper
SCIENCE	3.308.500	−6.316	<0.001*	−0.555	−0.663	−0.425
MATH	1.511.500	−7.852	<0.001*	−0.737	−0.810	−0.641
ENGINEERING	2.771.000	−6.853	<0.001*	−0.610	−0.708	−0.488
TECHNOLOGY	1.271.000	−11.629	<0.001*	−0.898	−0.924	−0.865
STEM	2.393.500	−6.370	<0.001*	−0.594	−0.699	−0.463

findings support the conclusion that similar patterns were observed across genders (Fig. 4).

As shown in Fig. 4, gender differences in STEM perception were minimal, with similar scores for both males and females at both time points.

To corroborate these findings, a Chi-square (X^2) analysis was conducted. Table 8 presents the results, including degrees of freedom (df), p-values, and effect size (Cramer's V).

Cramer's V effect size reveals that prior to the intervention, Engineering showed the most significant gender gap ($V = 0.350$), which decreased after the program ($V = 0.200$), suggesting a reduction in gender disparity. Math and Science perceptions remained relatively stable. While overall STEM perception showed a slight increase in effect size (from 0.228 to 0.275), it did not indicate any bias introduced by the intervention.

To further explore individual-level changes, participants were categorized into three groups based on their perception change: improvement, no change, or worsening (Fig. 5).

The data show that the program positively affected STEM perceptions among both genders. Female students showed greater improvements in Science and Mathematics, while male students improved more in Technology. Engineering remained the most resistant area for both groups. Overall, most participants improved, with few showing no change or worsening, suggesting the program effectively stimulated interest in STEM while highlighting the need for tailored strategies in specific domains.

Table 6
Wilcoxon test for changes in career choice, ability, and success perceptions.

PRE-TEST VS. POST-TEST	W	Z	P	ES	95% CI	
					Lower	Upper
Math career	2.244.000	−0.806	0.404	−0.093	−0.310	0.132
Science career	3.101.000	−1.100	0.251	−0.117	−0.314	0.090
Technology career	2.850.000	−0.446	0.643	−0.049	−0.259	0.165
Engineering career	3.081.000	−1.713	0.078	−0.179	−0.367	0.024
Math ability	2.144.000	−1.757	0.069	−0.199	−0.401	0.020
Science ability	2.851.500	−0.755	0.436	−0.083	−0.289	0.131
Engineering success	2.542.500	−1.664	0.088	−0.182	−0.379	0.030
Technology success	2.737.500	−1.667	0.084	−0.179	−0.373	0.029

Table 7
Mann-Whitney *U* test by gender.

	PRE-TEST			POST-TEST		
AREAS STEM	U	P	ES	U	P	ES
SCIENCE	7.301.000	0.163	0.105	6.907.000	0.53	0.05
MATH	7.453.500	0.088	0.129	7.179.000	0.23	0.09
ENGINEERING	7.218.000	0.22	0.093	7.095.500	0.31	0.07
TECHNOLOGY	6.590.500	0.978	−0.002	6.905.500	0.53	0.05
STEM	6.981.000	0.45	0.057	7.130.000	0.27	0.08

In addition to gender, STEM perception was analyzed by region, as the Retos Indigenius: Inspiring Futures in STEM project was implemented in two distinct sociocultural contexts. This comparison allows for examining how geographical differences may influence program effectiveness (Table 9).

The analysis revealed no significant differences in STEM perception between the two regions ($p > 0.05$), suggesting that the intervention had a uniform effect across geographic contexts. This indicates that the program was equally effective in both sociocultural settings.

Fig. 6 shows an increase in post-test scores in both regions. While Technology perception improved more in Region 1, Science saw greater gains in Region 2. Perception of Mathematics remained stable, and Engineering showed a slight decline in both regions, suggesting a need for reinforcement in this area. These findings highlight the importance of adapting strategies to each local context to maximize engagement. A Chi-square analysis was also conducted to further examine regional effects (Table 10).

Chi-square results confirm the absence of statistically significant regional differences ($p > 0.05$). However, effect size (Cramer's V) reveals some minor variations: for example, Engineering perception became more homogeneous post-intervention, while Technology showed the most significant regional difference after the program. Overall, the intervention appeared to reduce regional disparities in STEM perception.

To capture changes at the individual level, students were again categorized by perception shifts (improved, no change, worsened) by region (Fig. 7).

The results indicate a positive evolution in STEM perception in both regions. More than 50% of students improved their perception in Science, Mathematics, and Engineering, with Technology showing the greatest improvement (over 88% of students). Overall STEM perception improved more in *San Cristóbal de las Casas, Chiapas* (52.5%) than in *Cadereyta Jiménez, Nuevo León* (42.7%). Although some students showed no change or worsening in perception, these were a minority. These results confirm that the program effectively boosted motivation and interest in STEM, particularly in the area of Technology.

5. Discussion

5.1. Impact on STEM perceptions

The findings of this study suggest that the Retos Indigenius: Inspiring Futures in STEM intervention was associated with positive changes in students' perceptions of STEM disciplines, as evidenced by the differences observed between pre-test and post-test measurements. These results indicate that challenge-based and hands-on learning approaches may help improve students' attitudes toward STEM, particularly in educational environments where exposure to these disciplines is limited.

This observation is consistent with previous research highlighting the role of experiential and inquiry-based activities in fostering engagement and interest in STEM learning (Hidi & Renninger, 2006; Maltese & Tai, 2011). The descriptive analyses revealed improvements across all STEM domains, with the most pronounced changes observed in Technology and Mathematics. Inferential analysis using the Wilcoxon test confirmed statistically significant differences between pre- and post-test scores across all domains ($p < 0.001$), suggesting meaningful changes in students' perceptions following the intervention.

Among the different disciplines, perceptions of Technology showed the largest change, shifting from routine ($M = 2.02$) to fascinating ($M = 4.37$), with a very large effect size ($Z = -11.629$, $p < 0.001$). One

Table 8
Chi-square analysis of STEM perceptions by gender.

AREAS STEM	PRE-TEST				POST-TEST			
	X^2	df	p	Cramer's V	X^2	df	p	Cramer's V
SCIENCE	8.43	18	0.97	0.19	12.77	17	0.75	0.24
MATH	16.56	20	0.68	0.27	13.17	17	0.73	0.24
ENGINEERING	28.20	20	0.11	0.35	9.24	15	0.86	0.20
TECHNOLOGY	13.16	12	0.36	0.24	13.43	14	0.49	0.24
STEM	12.00	17	0.80	0.23	17.38	14	0.24	0.28

Table 9
Mann-Whitney *U* test by region.

	PRE-TEST			POST-TEST		
AREAS STEM	U	p	ES	U	p	ES
SCIENCE	6.751.000	0.763	0.023	6.705.500	0.828	0.016
MATH	6.905.500	0.539	0.046	6.851.000	0.602	0.038
ENGINEERING	6.851.000	0.616	0.038	6.607.500	0.989	0.001
TECHNOLOGY	6.141.500	0.355	−0.069	6.196.500	0.401	−0.061
STEM	7.155.000	0.265	0.084	6.581.000	0.969	−0.003

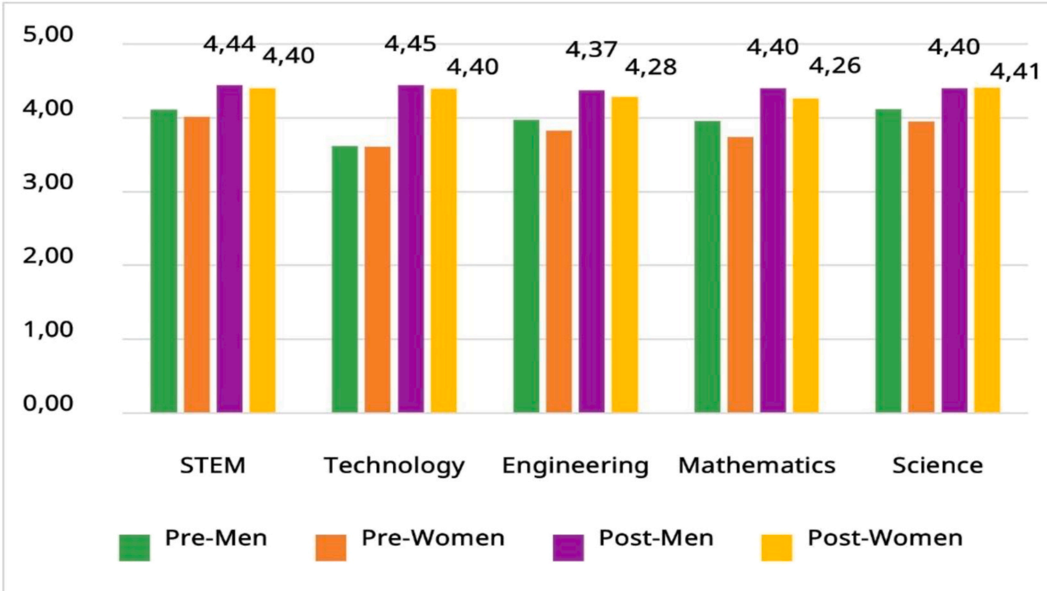

Fig. 4. Comparison of pre-test and post-test means by gender.

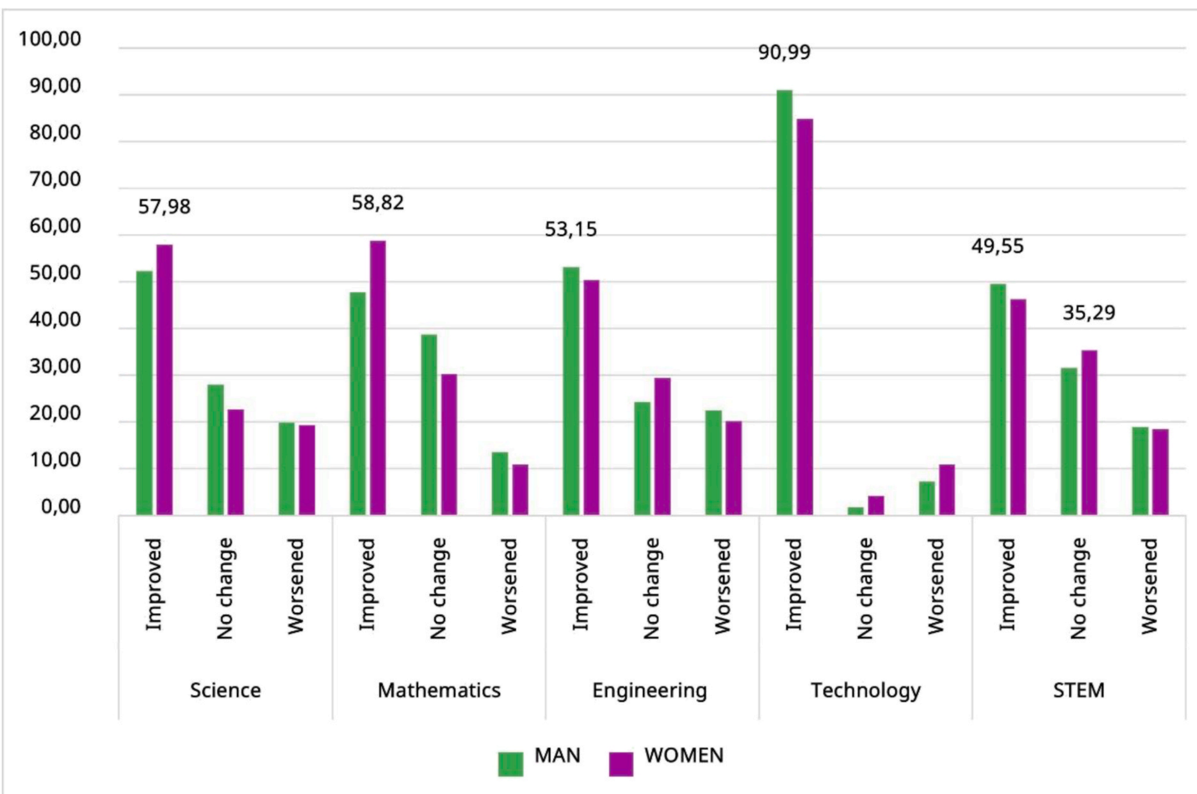

Fig. 5. Change in STEM perception by gender (%).

possible explanation is that the subject's initially low valuation created greater potential for improvement during the intervention. The design of the challenges, which emphasized experimentation and real-world problem solving, may have contributed to reframing technology-related activities as creative and engaging learning experiences.

This transformation aligns with the principles of STEM education, which emphasize interdisciplinary learning and the integration of Science, Technology, Engineering, and Mathematics to connect theoretical knowledge with practical applications (Mateos Núñez, 2021). By engaging students in collaborative, problem-oriented tasks, the intervention appears to have fostered more positive perceptions of these disciplines.

However, when examining specific variables such as career choice, self-perception of ability, and expectations of success in STEM, the observed improvements were moderate and not statistically significant. This pattern suggests that while short-term interventions may influence

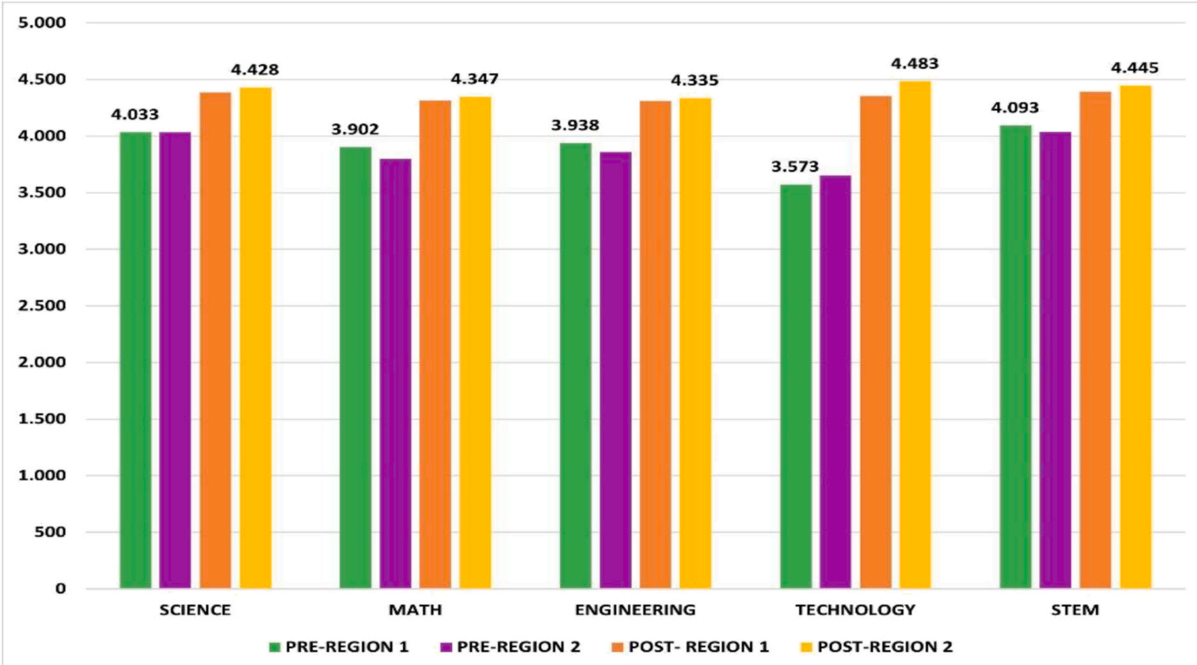

Fig. 6. Comparison of pre- and post-test means by region.

Table 10
Chi-square analysis of STEM perceptions by region.

	PRE-TEST				POST-TEST			
AREAS STEM	X^2	df	p	Cramer's V	X^2	df	p	Cramer's V
SCIENCE	24.063	18	0.153	0.323	17.145	17	0.445	0.273
MATH	18.062	20	0.583	0.286	17.952	17	0.392	0.279
ENGINEERING	18.868	20	0.530	0.286	16.046	15	0.379	0.264
TECHNOLOGY	8.829	12	0.717	0.196	19.978	14	0.131	0.295
STEM	22.857	17	0.154	0.315	9.395	14	0.805	0.202

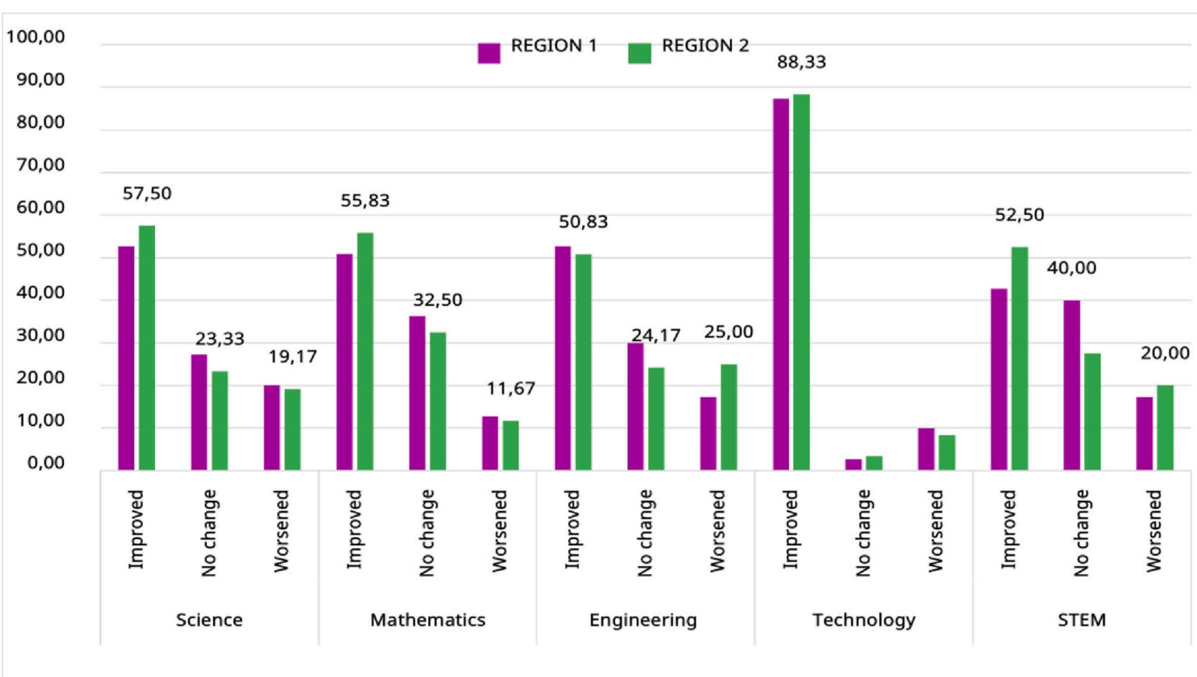

Fig. 7. Evolution of Perception in STEM areas by region (%).

general attitudes toward STEM, changes in vocational aspirations typically require longer periods of exposure and reinforcement. Previous research indicates that career-related expectations are shaped by cumulative educational experiences, mentoring relationships, and sustained engagement with STEM learning environments (Aguilera & Perales-Palacios, 2020; Eccles & Wang, 2016).

In this sense, STEM educational initiatives may play an important role in introducing students to scientific and technological fields and in developing foundational competencies that gradually contribute to long-term interest. As noted by Ata-Aktürk and Demircan (2017), early exposure to STEM learning experiences can support the development of scientific literacy and key competencies essential for sustained engagement in these domains.

5.2. Equity effects across gender and region

The inferential analyses (Wilcoxon and Mann–Whitney tests) also indicated that the observed improvements in STEM perceptions were not significantly conditioned by gender or region. This finding is particularly relevant, as it suggests that the intervention was associated with relatively consistent changes across different sociocultural contexts without reinforcing pre-existing disparities in STEM engagement.

Previous studies have highlighted persistent gender differences in attitudes toward STEM disciplines, often emerging during late primary or secondary education (Sadler et al., 2012). In this context, the absence of statistically significant gender differences in the outcomes of this intervention may indicate that early exposure to inclusive and collaborative STEM activities can support more equitable learning experiences.

Although minor regional variations in STEM perception were observed, these differences appear to be related to the specific challenges implemented in each setting. In Region 1, the activities “Toothpick and Jelly Bean Lattices” and “Edible DNA” emphasized structural engineering and molecular biology concepts. In Region 2, the challenges “Secret Messages with a Cypher Disk,” “Culinary Algorithms,” and “Zero-Mile Food” addressed topics such as cryptography, computational thinking, and food sustainability.

These variations illustrate how different thematic approaches within challenge-based learning can emphasize distinct aspects of STEM competencies, such as logical reasoning, procedural thinking, and ecological awareness.

5.3. Cultural adaptation and contextualized learning

An important feature of the intervention was the contextual adaptation of the challenges to local cultural environments. In particular, activities implemented in Region 2 incorporated elements related to food traditions and local practices, which may have contributed to strengthening students’ engagement by connecting STEM concepts with everyday experiences.

Previous research suggests that culturally responsive learning environments can enhance students’ sense of belonging and participation in science education (Brown et al., 1989; Wang & Degol, 2017). Integrating culturally meaningful practices such as food preparation, local traditions, or community knowledge within STEM learning activities can increase the perceived relevance of these disciplines and support more inclusive educational experiences (Payà Rico & Tormo Tormo, 2016).

From this perspective, culturally contextualized STEM learning may contribute not only to improving student engagement but also to supporting the participation of historically underrepresented groups in science education. Incorporating cultural values, community practices, and locally meaningful contexts into STEM instruction aligns with broader approaches to culturally responsive pedagogy (Paredes Palacios, 2019). Such strategies can help create learning environments where students from diverse backgrounds perceive STEM disciplines as accessible and relevant to their lives (Fonseca-Factos & Simbaña-Gallardo, 2022).

5.4. Strengths and contributions of the study

This study presents several methodological and contextual strengths. First, it examines the implementation of a culturally contextualized challenge-based STEM intervention in semi-urban and rural schools serving Indigenous student populations, a context that remains underrepresented in international STEM education research. The relatively large sample size ($n = 230$) strengthens the reliability of the findings within these educational settings.

Second, the study employed a previously validated instrument to assess students’ perceptions and attitudes toward STEM disciplines, contributing to methodological rigor. Reporting effect sizes alongside significance tests further enhances the transparency and interpretability of statistical analyses.

Third, the intervention design emphasized authentic, hands-on learning experiences using accessible materials aligned with the cultural and community context of participating schools. This alignment between pedagogical design, cultural context, and evaluation framework represents a key methodological contribution for research seeking to promote equitable STEM education in rural and marginalized communities.

Finally, the study contributes to addressing a notable gap in STEM education research conducted in Global South contexts, particularly in rural and Indigenous educational environments that remain underrepresented in the international literature.

5.5. Educational implications and future directions

Taken together, these findings highlight the potential value of culturally responsive challenge-based STEM activities in semi-urban and rural primary education contexts. Although the intervention was relatively short, the results suggest that hands-on learning experiences may improve students’ perceptions of STEM disciplines and support more inclusive participation.

Future educational initiatives may benefit from complementing short-term interventions with longer-term strategies such as mentoring programs, sustained STEM clubs, and structured vocational guidance. These approaches could reinforce students’ self-efficacy and support the gradual development of career aspirations in science and technology fields.

At the policy level, the results support current educational priorities in Mexico aimed at promoting inclusive STEM education. National initiatives such as the National Program for the Promotion of STEM Education and the National Digital Education Strategy emphasize the importance of reaching historically marginalized rural and Indigenous communities (Secretary of Education of the Government of the State of Yucatán, 2023; Secretary of Public Education, 2018). These objectives are also aligned with Sustainable Development Goal (SDG) 4, which promotes inclusive and equitable quality education, and SDG 10, which aims to reduce inequalities within and among societies (UNESCO, 2023).

Overall, the evidence from this study suggests that culturally responsive, challenge-based learning approaches may represent a promising pathway for supporting equitable STEM education. Further research could explore the long-term effects of similar interventions, incorporate qualitative data to better understand students’ learning experiences, and examine the role of mentoring and community engagement in shaping STEM trajectories among rural and Indigenous youth.

6. Conclusions

The findings of this study indicate that the Retos Indigenius: Inspiring Futures in STEM project was associated with positive changes in students’ perception of STEM, with significant improvements particularly in the assessment of Technology and Mathematics.

However, no substantial changes were observed in career choice or self-perception of skills, suggesting the need for complementary strategies to further support these dimensions. Additionally, the results demonstrate that the intervention benefited all groups equally, with no observed bias based on gender or region.

A key contribution of the Retos Indigenius: Inspiring Futures in STEM initiative lies in its culturally contextualized design. While it was inspired by the challenges developed by faculty at the University of Salamanca through the All WE Are STEAM project, all activities were adapted and contextualized to reflect the specific realities of the environments where they were implemented. This adaptation ensured that the challenges were culturally relevant and aligned with students' needs, backgrounds, and prior knowledge. Unlike its methodological predecessor, Retos Indigenius: Inspiring Futures in STEM distinguished itself by directly engaging with local issues in rural and Indigenous communities, resulting in an educational proposal that is more authentic, meaningful, and transformative for students navigating diverse sociocultural contexts.

Several limitations should be considered when interpreting these findings. First, the absence of a control group limits the ability to establish causal relationships between the intervention and the observed outcomes. Second, the short duration of the intervention may have been insufficient to produce sustainable impacts on vocational choice or students' confidence in their STEM abilities. Furthermore, the study was limited to a sample from two specific regions in Mexico, which restricts the generalizability of the findings to other educational settings. In addition, the study relied on self-reported measures, which may be affected by response bias. Contextual factors, such as teacher influence or differences in school resources, were not fully controlled and may have influenced the results. Finally, the absence of qualitative data limits a deeper understanding of students' learning experiences and perceptions of the activities.

Despite these limitations, the findings highlight the potential value of culturally responsive STEM programs for promoting engagement in underserved educational settings. Educational initiatives in rural and Indigenous communities may benefit from extending program duration and incorporating complementary strategies, such as teacher professional development, culturally responsive instructional materials, mentoring initiatives, and early vocational guidance. At the policy level, these results support the importance of promoting inclusive STEM education strategies that address the needs of historically marginalized communities.

Future research could explore the long-term effects of similar interventions and examine how mentoring programs and sustained STEM engagement activities influence students' educational trajectories. Studies incorporating control groups and mixed-method approaches would also strengthen the evidence base regarding the impact of culturally contextualized STEM education initiatives.

CRediT authorship contribution statement

Erika García-Silva: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alicia García-Holgado:** Writing – review & editing, Validation, Supervision, Methodology. **María Cruz Sánchez-Gómez:** Writing – review & editing, Validation, Supervision, Methodology. **Sonia Verdugo-Castro:** Writing – review & editing, Validation, Methodology.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the University of the University of Salamanca (Reference number: 1037). The study complied with institutional and international ethical standards for research involving human participants. Participation was voluntary, and informed consent was obtained from the participating schools and teachers prior to data collection.

Availability of data and materials

The data sets presented in this article are not readily available because of confidentiality and anonymity, but they can be requested from the corresponding author.

Ethics approval and consent to participate

Ethical approval was granted by the Research Ethics Committee of the University of Salamanca under registration number 1037. The participants' legal guardians/next of kin provided written informed consent for participation in this study.

Declaration of the use of AI

The authors used AI-assisted tools solely for language editing and translation support. No AI tools were used for data analysis, interpretation, or manuscript drafting.

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Declaration of competing interest

The authors declare that they have no competing interests.

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Data availability

The data that support the findings of this study are available on request from the corresponding author.

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