Perceived epistemological obstacles to low female participation in STEM: A study in southern Yucatán

Obstáculos epistemológicos percibidos en la baja participación femenina en STEM: estudio en el sur de Yucatán

Rennata González Ruíz
Maestría en Investigación Educativa, Universidad Autónoma de Yucatán (UADY), México.
a20211442@alumnos.uady.mx
https://orcid.org/0009-0004-9509-0615

J. Gabriel Domínguez Castillo
Maestría en Investigación Educativa, Universidad Autónoma de Yucatán (UADY), México.
jg.dominguez@correo.uady.mx
https://orcid.org/0000-0002-2897-913X

Edit Romero Pavía
Acompañamiento a escuelas (SAAE), Secretaría de Educación del Gobierno del Estado de Yucatán (SEGEY), México.
edit.romero.pavia@gmail.com
https://orcid.org/0009-0006-2379-7288

Margarita Bakieva-Karimova
Métodos de Investigación y Diagnóstico en la Educación. Universidad de Valencia, España.
margarita.bakieva@uv.es
https://orcid.org/0000-0002-2716-0755

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Corresponding author
Rennata González Ruíz
a20211442@alumnos.uady.mx

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Abstract

Science, Technology, Engineering, and Mathematics (STEM) disciplines have established themselves as key catalysts for national development worldwide, driven primarily by their role in fostering innovation, growth, and competitiveness. However, this progress is hindered by structural inequalities that give rise to epistemological obstacles contributing to low female participation in these fields. These obstacles are characterized by barriers or difficulties rooted in deeply ingrained beliefs, everyday experiences, and traditional concepts that impede the advance of critical thinking and the generation of new scientific ideas. This study employed a descriptive quantitative approach with a non-experimental design. The target population comprised female students enrolled in Computer Systems, Biochemical, Civil, Industrial, and Mechatronics Engineering programs across two higher education institutions in southern Yucatán. The findings reveal that the gender gap is not merely a numerical phenomenon, but rather a systemic construct of barriers that constrain the development of scientific inquiry. These results are discussed within the framework of official reports by UNESCO (2020) and the World Economic Forum (WEF, 2021).

Keywords: STEM, epistemological obstacles, structural inequalities, low female participation.

Resumen

Las áreas de Ciencia, Tecnología, Ingeniería y Matemáticas (STEM, por sus siglas en inglés) se han consolidado como las áreas que catalizan el desarrollo de los países del mundo, principalmente por su impulso en los procesos de innovación, desarrollo y competitividad. Sin embargo, este desarrollo se ve empañado por las desigualdades estructurales que provocan obstáculos epistemológicos en la poca participación femenina en estas áreas. Dichos obstáculos se caracterizan por ser, barreras o dificultades que surgen de creencias arraigadas, experiencias cotidianas e ideas tradicionales que entorpecen el avance del pensamiento y el desarrollo de nuevas ideas científicas. Este estudio se realizó bajo el enfoque cuantitativo descriptivo con un diseño no experimental. La población objetivo fue un grupo de mujeres que se matricularon en programas de Ingeniería en Sistemas Computacionales, Bioquímica, Civil, Industrial y Mecatrónica de dos instituciones de Educación Superior ubicadas en el sur del estado Yucatán. Los resultados muestran que la brecha de género no es simplemente un fenómeno numérico o único, sino una construcción sistémica de barreras que restringen el desarrollo del espíritu científico. Estos resultados se discuten bajo los documentos oficiales de la UNESCO (2020) y el World Economic Forum (WEF, 2021).

Palabras clave: STEM, obstáculos epistemológicos, desigualdades estructurales, baja participación femenina.

Introduction

Science, Technology, Engineering, and Mathematics (STEM) fields have established themselves as fundamental pillars in the contemporary world, constituting a foundation for national development and growth and serving as vital drivers of the global economy. Since the National Science Foundation (NSF) promoted the adoption of this acronym in the 1990s, its relevance has evolved far beyond the mere combination of these disciplines, transforming into a benchmark for progress, innovation, and global leadership (Britannica, 2026; Kayan-Fadlelmula et al., 2022; Moyo & Phiri, 2024). In today's context of digitalization, artificial intelligence, and the knowledge economy, strengthening these fields has become a strategic factor in boosting productivity and delivering solutions to the complex challenges of modern societies. However, this reinforcement is hindered by epistemological barriers and deep-seated structural inequalities that have contributed to the low participation of women in STEM (Beroíza-Valenzuela, 2025; Beroíza-Valenzuela & Salas-Guzmán, 2024; Silbiger & Stubler, 2019).

The present study establishes an operational objective: to identify and describe the epistemological obstacles perceived by women enrolled in STEM programs across two public higher education institutions in southern Yucatán, and to descriptively compare these perceptions across academic disciplines (science, technology, engineering, and mathematics) as well as by the participants' employment status. This objective entails three research questions: (1) What are the predominant epistemological obstacles perceived by female students? (2) Does this perception vary across the four STEM fields? and (3) Are there descriptive differences in the perception of obstacles based on the participants' employment status? These questions correspond directly to the dimensions of the EMA-STEM instrument and to the analytical framework outlined in the methodology section, thereby establishing a clear bridge between theory, methodology, and empirical findings. Ultimately, this study aims to contribute to the discourse on gender equity in higher education from a region typically underrepresented in specialized literature, demonstrating that the gender gap manifests not only in enrollment rates, but also through symbolic and structural barriers that impede women's retention and advancement in STEM fields.

Literature Review

Epistemological Obstacles and their Conceptual Definition

Women's participation in STEM is not merely a demand of social equity, but also a requirement for scientific objectivity and rigor. In this sense, the premise that science does not advance automatically leads to the recognition of what Bachelard (2000) conceptualizes as epistemological obstacles: internal barriers or cognitive instabilities embedded within research reasoning that impede the transition from everyday logic to scientific thinking. According to Bachelard, the difficulty in achieving objective understanding arises not from the inherent complexity of phenomena, but from these cognitive limitations of the conscious subject itself. To address the recommendation to delimit this concept, an epistemological obstacle is understood in this study in a strict sense as a barrier in an individual's relationship with knowledge (in its production, appropriation, and validation), and is distinguished analytically from various interrelated barriers: psychosocial barriers (self-efficacy, self-concept, motivation), institutional barriers (policies, curricula, and structures that construct a male "average student"), and cultural barriers (gender roles and stereotypes). Rather than replacing these broader barriers, the epistemological obstacle marks the precise point at which they become an impediment to women perceiving themselves—and being recognized by others—as true creators of scientific knowledge.

Within this framework, scholarly literature has reached a consensus that science is not a linear succession of discoveries, but rather a continuous process of breaking away from prior knowledge (Bachelard, 1938/2000; Cech & Waidzunas, 2021; Cheryan et al., 2017; Master et al., 2021). Beyond broad theoretical analyses of gender gaps (e.g., Vargas & Domínguez, 2026), this study aims to fill the empirical gap regarding the perception of these obstacles within regional contexts in southeastern Mexico.

Four Dimensions of Epistemological Obstacles in STEM

Building upon this framework, four distinct dimensions are delineated that collectively constitute the epistemological obstacles encountered by women in STEM. Subsequently, each of these dimensions is operationalized within a subscale of the EMA-STEM instrument (see Methodology section).

Family Support (Epistemological Insecurity)

The family represents the primary locus of initial engagement with knowledge, wherein the momentum of traditional culture operates; for a young woman, choosing a STEM career does not occur in a social vacuum, but within an established framework that dictates gender roles. Familial stereotypes function as a preconceptive "opinion" that precludes viewing women as agents of technological change (UNESCO, 2017); the absence of encouragement and the persistence of traditional caregiving expectations generate a burden that restricts the initial development of a scientific mindset.

Validation Biases

The second-dimension manifests through institutional and community biases that operate under what De Sousa Santos (2011) terms the "sociology of absences." This constitutes not a fortuitous omission, but an active producing of the subject's absence within a field of knowledge. In higher education, this obstacle materializes when women's contributions and perspectives are deliberately devalued or ignored, resulting in a "waste of social experience."

Gender Stereotypes

The third dimension is expressed through language and social interaction. Stereotypes are not harmless labels: they function as an "opinion" that "thinks poorly" and rejects women's intellectual potential based on unfounded customs (Bachelard, 1938/2000), generating a conflict between students' identity and traditional beliefs (UNESCO, 2017). Drawing on Habermas (1981/1999), these stereotypes exert a subtle yet effective coercion, distorting communication by silencing women's voices in classrooms, laboratories, and research projects, while eroding their support and mentorship networks due to a scarcity of role models.

Gender Inequality

The fourth dimension pertains to an administrative structure that is far from neutral, but rather permeated by a "microphysics of power" (Foucault, 1975/2002). Technological universities operate through specialized mechanisms that have historically adopted a model establishing a male standard for the expert or scientist. This structure functions as an invisible barrier that compels women—whose trajectories often involve caregiving responsibilities or distinct mobility patterns—to "masculinize" their behavior or, in more severe instances, to withdraw from these academic communities; furthermore, this inequality persists throughout the transition into the labor market.

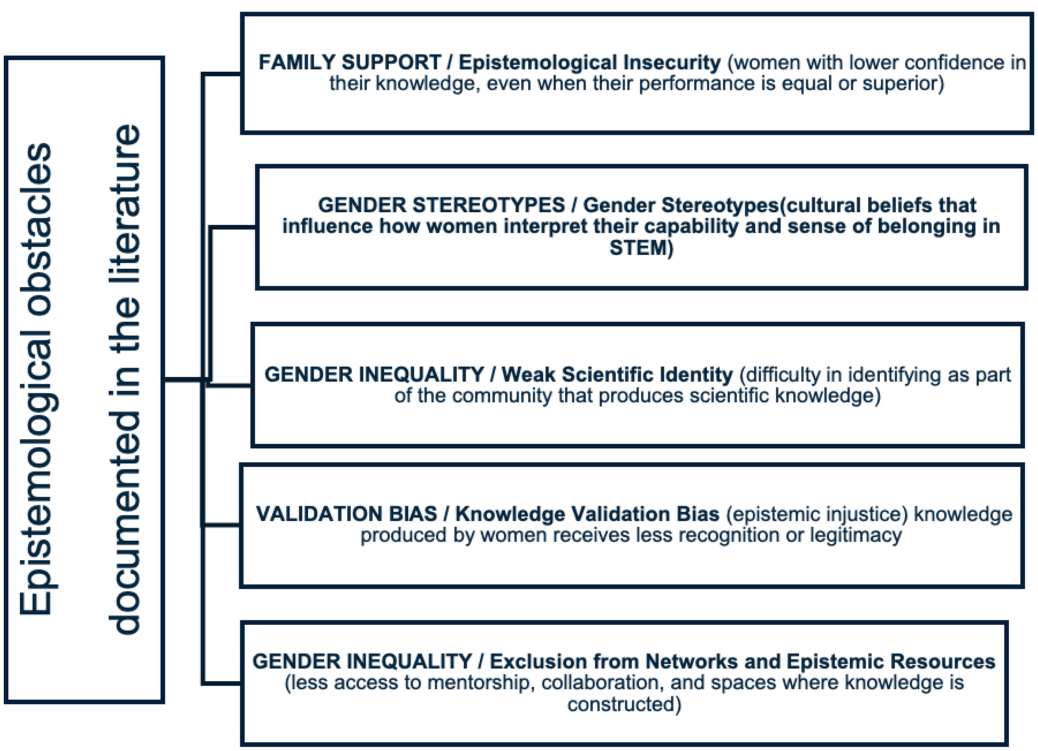

Figure 1.
Primary Epistemological Obstacles

Bibliometric Review: Procedure

To map the thematic landscape of the field, a bibliometric co-occurrence analysis of keywords was conducted using VOSviewer software. Documents were retrieved from the Scopus database using the following search string: ("STEM" OR "science, technology, engineering and mathematics") AND ("gender gap" OR "gender inequality" OR "gender equity" OR "women" OR "female"). The search applied no language restrictions and was limited strictly to scientific articles within STEM fields. From the 200 records exported in .ris format, a co-occurrence map was generated, setting a minimum threshold of four occurrences per keyword.

The map (Figure 1) demonstrates thematic centrality around the nodes stem, gender, gender gap, and gender inequality, confirming that the literature primarily focuses on the intersection of gender and STEM education, consistent with the framework of the EMA-STEM instrument (Domínguez Castillo et al., 2019, 2020; Vargas-Jiménez et al., 2026). Approximately five to six thematic clusters can be identified: (a) STEM and stereotypes (stem, stereotypes, discourse, and materiality); (b) inequality and higher education (higher education, gender equality, gender inequality, gender difference, diversity, horizontal stratification); (c) STEM education and academic trajectories (STEM education, formal STEM learning, gender representation, academic career, university course choice); (d) social and familial factors (parenthood, child penalty, gender gaps, mathematical knowledge, expectations); (e) gender and cognition (gender, cognition, cognitive health expectancies); and (f) equity (gender equity) serving as a bridging node between clusters.

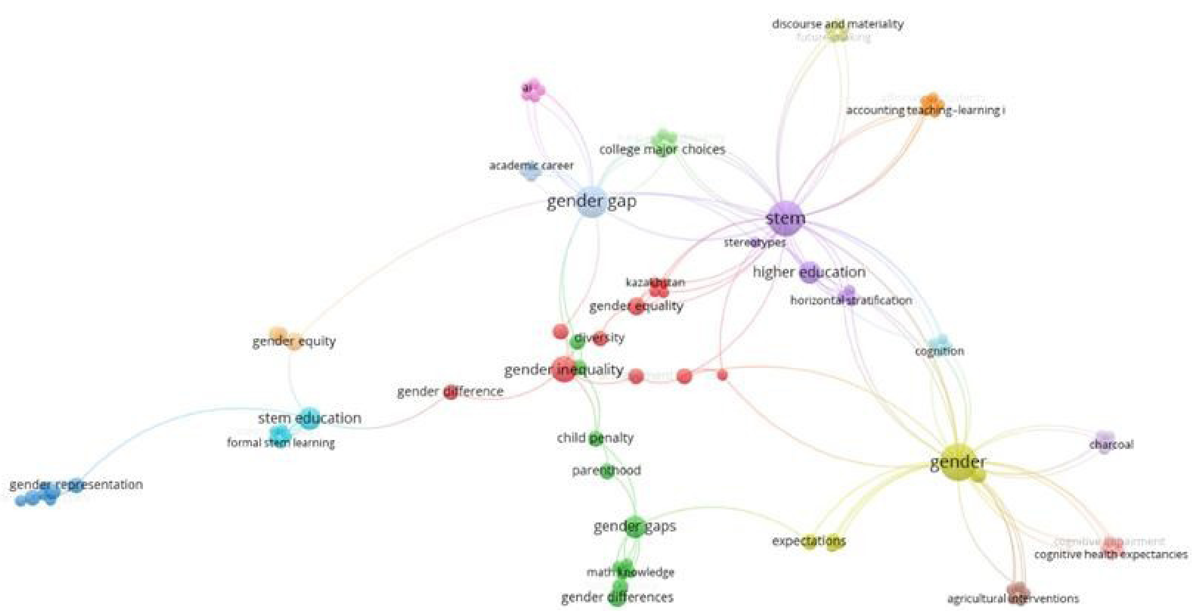

Figure 2. Bibliometric Analysis of Nodes and Clusters

Methodology

Design and Approach

A quantitative descriptive study with a non-experimental, cross-sectional design was conducted utilizing convenience sampling to reinforce theoretical principles (Hernández-Sampieri & Mendoza-Torres, 2023). The objective was to utilize data-driven analysis to identify the epistemological obstacles encountered by women in STEM fields within Latin American contexts—specifically in southern Yucatán, Mexico, during 2025—thereby extending the study beyond theoretical philosophy and bringing visibility to often-overlooked social phenomena. Given its strictly descriptive nature, the reporting of results refrains from utilizing inferential or causal language.

The design incorporates a gender perspective across three structural levels: (a) the unit of analysis is centered on women in STEM; (b) each measured dimension derives from a theoretical framework explaining the systemic exclusion of women from scientific knowledge (family support, validation biases, stereotypes, and inequality); and (c) the interpretation of findings is conducted in light of historical contexts and official metrics regarding gender disparities (UNESCO, 2017, 2020; World Economic Forum, 2021). Consequently, the measurement process is not gender-neutral, but explicitly engages with mechanisms governing the production and validation of knowledge.

Population, Institutions, and Sample

The target study population comprised women enrolled in STEM degree programs at two public higher education institutions located in the rural region of southern Yucatán, Mexico. Both public institutions were deliberately selected because they offer established STEM degree programs in this area and are situated in the deep south—a region characterized by significant socio-economic disadvantage—thereby facilitating an in-depth examination of the STEM landscape within this specific regional context.

For reasons of institutional confidentiality, the two entities are anonymized as IES-1 and IES-2. The final sample consisted of 83 women, obtained through a non-probability convenience sampling method involving students enrolled during the data collection periods (November–December 2024 and March–April 2025). The sample distribution across institutions was as follows: IES-1 ($n = 44$) and IES-2 ($n = 39$).

The inclusion criteria were: (1) being enrolled in a STEM degree program at either of the two participating universities; (2) self-identifying as female; and (3) granting informed consent to participate voluntarily in the research. Incomplete questionnaires were excluded. It should be noted that the sample size for the mathematics discipline was limited to 2 participants, owing to the extremely low enrollment of female students in this degree program and the fact that only these 2 individuals voluntarily agreed to participate in the study.

Table 1.
Distribution of Participants by STEM Area

STEM Area	f	%
Science	35	42.2
Technology	18	21.7
Engineering	28	33.7
Mathematics	2	2.4
Total	83	100

Instrument

Data collection was conducted using the EMA-STEM instrument, which operationalizes dimensions of women's experiences in STEM and translates complex social phenomena into quantifiable variables. The instrument is structured into two main sections: (1) personal and sociodemographic background, designed to profile the participants and their immediate context; and (2) contextual factors, comprising dimensions directly linked to the epistemological obstacles identified in the literature (family support, gender biases, gender inequalities, and network exclusion). Each item was rated on a five-point Likert scale (1 = Strongly disagree; 5 = Strongly agree), where higher scores reflect a greater perception of the obstacle (Table 2).

Table 2.
Relationship between EMA-STEM domains and epistemological obstacles

Domain	Epistemological Obstacles	N.° of ítems	Scale
Family support	Epistemological uncertainty	17	Likert 1–5
Gender biases	Validation biases	10	Likert 1–5
Gender stereotypes	Gender stereotypes	8	Likert 1–5
Exclusion in social networks	Weak scientific identity / exclusion from networks	11	Likert 1–5

Sample items (one per domain): family support ("My family believed that STEM careers were not suitable for me"); validation biases ("I have felt that my technical contributions are questioned because I am a woman"); gender stereotypes ("In class, it is assumed that men have a greater natural aptitude for STEM subjects"); network exclusion ("I have had less access to networks or mentorship compared to my male peers").

Regarding validity testing, content validity was established through expert judgment, involving four experts in social psychology, two experts in gender studies, and one expert in STEM. In terms of reliability, the instrument demonstrates satisfactory global indicators (α de Cronbach = .89; ω de McDonald = .91) (Vargas-Jiménez et al., 2026) within the present data collection.

Ethical Considerations

Participation was voluntary and anonymous; each student provided prior informed consent, supported by an institutional authorization document granting permission to administer the instrument. No personally identifiable data were collected, and all information was protected solely for academic purposes, thereby ensuring complete confidentiality.

Data Analysis Plan

Data were processed using descriptive statistics. For each dimension, scale scores were computed as the mean of their constituent items, and measures of central tendency (mean, median) and dispersion (standard deviation) were derived. No missing data requiring imputation were identified. Results are presented through error bar charts and box plots; error bars correspond to 95% confidence intervals. Data processing was conducted using IBM SPSS Statistics software using descriptive statistics: for each dimension, scores were calculated by averaging its respective items to obtain measures of central tendency (mean, median) and dispersion (standard deviation). No missing values required registration, and findings are illustrated using error bar charts and box-and-whisker plots as presented in the following figures.

Results

As shown in Figure 3, the error bars represent the 95% confidence intervals (95% CI) associated with the specific estimates of each analyzed dimension, with the span of each bar indicating the lower and upper limits of the interval for each examined epistemological obstacle. As can be seen, the mathematics field exhibits greater estimation uncertainty due to the small sample size of women who participated in this study. Conversely, the fields of science, engineering, and technology display narrower intervals, reflecting higher precision in the statistical estimates.

The analysis of the perception of epistemological obstacles across these four STEM fields yields values that are relatively close to one another, with slight variations by field, as shown in the figure above (Figure 3). It is important to note that the observed means (ranging approximately from 1.4 to 2.8 on a 1-to-5 scale) are low in absolute terms; therefore, the disparities described in this analysis should be interpreted as relative levels across dimensions rather than high levels in a normative sense.

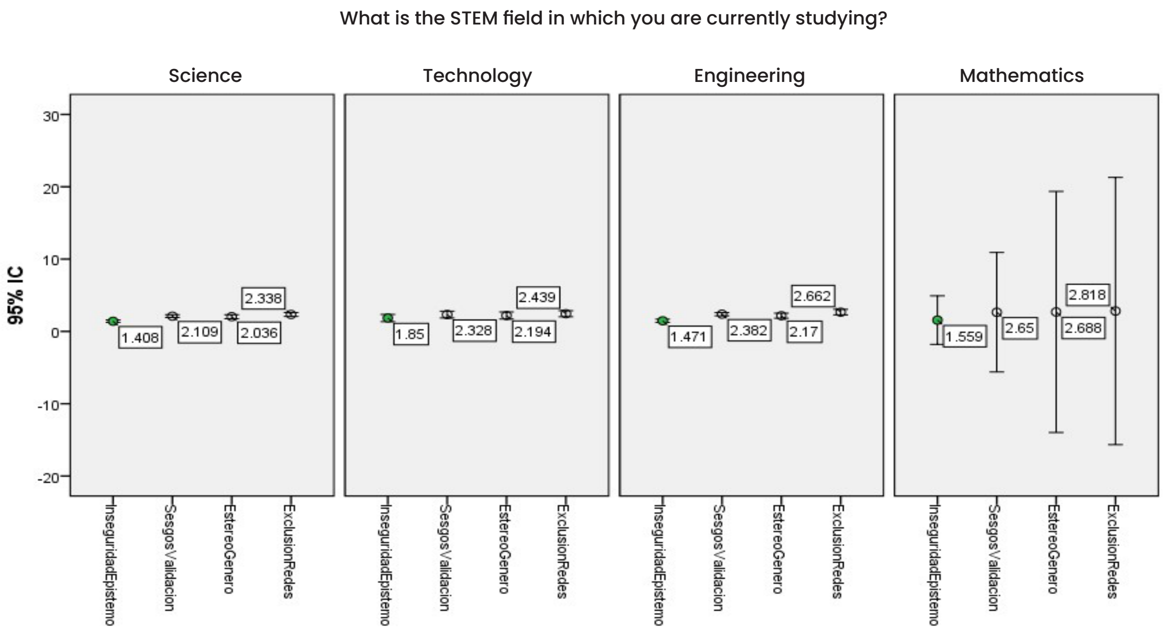

Figure 3.
Epistemological Obstacles by STEM Field

To begin, the perception of network exclusion is the highest across all fields: Science (M = 2.33), Technology (M = 2.43), Engineering (M = 2.66), and Mathematics (M = 2.81), suggesting that it represents the obstacle perceived with the greatest relative intensity. Second, engineering and mathematics generally exhibited slightly higher values across virtually all obstacles, particularly regarding exclusion and stereotypes. Third, epistemological insecurity was the lowest perceived obstacle, with values across the four fields ranging between 1.4 and 1.8. Fourth, gender stereotypes exerted a minimal yet stable impact (approximate values ranging between 2.0 and 2.7).

The table below (Table 3) presents a more in-depth and detailed descriptive analysis of the four epistemological obstacles, based on the premise that a higher score indicates a greater presence of the obstacle. First, network exclusion constitutes the obstacle with the highest relative presence, showing the highest means (M = 2.48) and medians (Md = 2.36), exceeding gender bias (M = 2.26), gender stereotypes (M = 2.13), and family support (M = 1.52). Furthermore, its third quartile reaches 3.27, indicating that at least 25% of the participants scored at or above this level. This suggests that structural conditions of inequality may represent a particularly relevant barrier within the analyzed phenomenon.

Second, stereotypes and network exclusion exhibit the greatest heterogeneity among the participants' experiences. The largest interquartile range (IQR) corresponds to network exclusion (IQR = 1.4545), followed by gender stereotypes (IQR = 1.3750). This indicates considerable dispersion within the middle 50% of responses. The standard deviation is also relatively high in both cases (0.895 and 0.898, respectively). Consequently, these obstacles do not appear to be experienced uniformly, meaning their intensity varies substantially among participants.

Third, family support records the lowest mean (M = 1.52), median (Md = 1.23), standard deviation (SD = 0.67), and IQR (0.588). The fact that the middle 50% of responses falls between 1.058 and 1.647 demonstrates a relatively tight concentration. This can be interpreted as an indication that, within the analyzed population, conditions related to family support represent a less widespread barrier with less variability than gender-related factors.

Fourth and finally, the differences between the mean and median point to a trend toward higher scores within a subset of the population. Across all four dimensions, the mean exceeds the median: family support (1.528 > 1.235), gender bias (2.261 > 2.200), gender stereotypes (2.131 > 2.000), and network exclusion (2.480 > 2.363). These disparities are particularly pronounced in family support and gender stereotypes, suggesting potential positive skewness: although a substantial proportion of participants reports relatively low or moderate scores, there exists another distinct subgroup that perceives considerably higher levels of the obstacle. Overall, the data demonstrate a consistent pattern: network exclusion, bias, and gender stereotypes exhibit higher overall levels than family support, along with greater dispersion. In particular, the fact that the middle 50% of participants is distributed across relatively wide intervals for network exclusion and stereotypes indicates that gender-based experiences are far from uniform across the sample population.

Table 3.
Means by Dimension and STEM Area (1–5 Scale)

		Family support	Gender Bias	Gender Stereotypes	Exclusion in Social Networks
N	Valid	83	83	83	83
	Missed	0	0	0	0
Mean		1.5287	2.2614	|2.1310	2.4808
Median		1.2353	2.2000	2.0000	2.3636
Standard Deviation		.67991	.66641	.89862	.89597
Variance		.462	.444	.808	.803
Percentiles	25	1.0588	1.8000	1.3750	1.8182
	50	1.2353	2.2000	2.0000	2.3636
	75	1.6471	2.8000	2.7500	3.2727

Subsequently, a key variable (employment status) was examined within this study of epistemological obstacles associated with low female participation in STEM fields, given its influence on how women access, interpret, and construct knowledge and expectations regarding their disciplines. From this perspective, work experiences shape not only the availability of material resources and time, but also exposure to role models, learning opportunities, and social representations concerning scientific and technological professions.

As illustrated in Figure 4, the following observations can be drawn: (1) women who are currently employed generally exhibit higher medians in validation biases, gender stereotypes, and network segregation, indicating a higher perception of these issues within the workplace environment; (2) epistemological insecurity maintains low values across both groups, with certain outlier values among those who are not employed; (3) variability increases within the employed group, particularly regarding stereotypes and exclusion, pointing to more diverse experiences; and (4) network exclusion stands out in both groups, identifying it as a prominent difficulty regardless of employment status.

Similarly, the box-and-whisker plot illustrates the behavior of the interquartile ranges (IQR), bounded by the first (Q1) and third (Q3) quartiles across each of the epistemological obstacles, compared against the dichotomous employment status variable—which was the sole key contrast variable

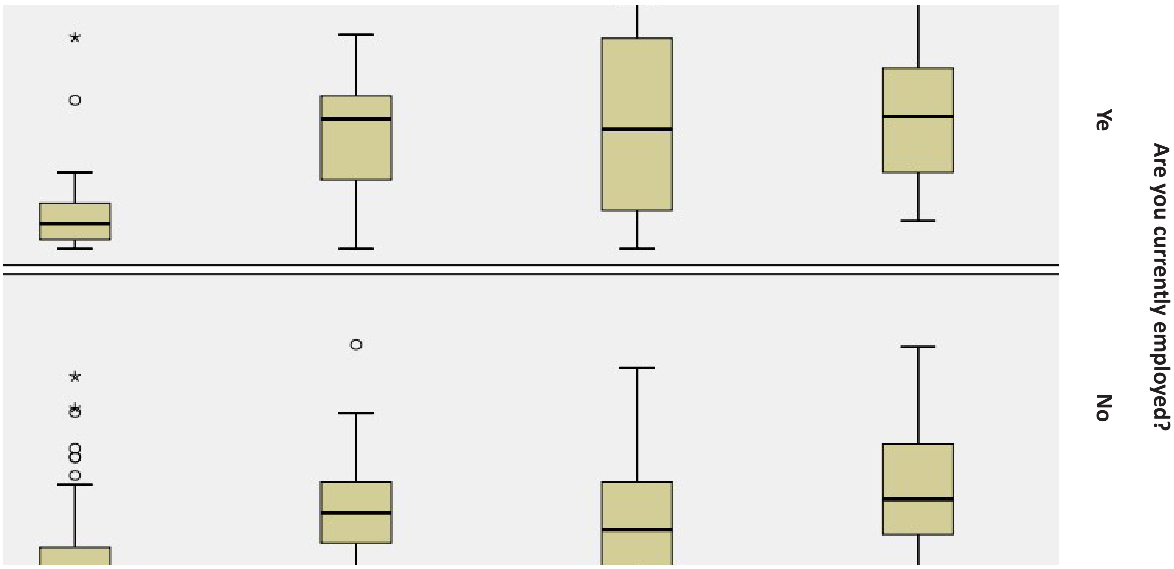

Figura 4. *Obstáculos epistemológicos según la condición labora*

regarding type of employment included in the questionnaire. The highest median value was observed for Domain 4 (Md = 2.48), suggesting that participants reported higher overall levels of perception or personal experiences associated with social network exclusion.

Discussion

The results make it possible to distinguish precisely between what the empirical research findings can confirm and what derives from theoretical frameworks and prior analyses. On a descriptive level, the data demonstrate that among the evaluated metrics, network exclusion exhibits the highest relative intensity, while epistemological complexity displays the smallest magnitude. The theoretical examination of these patterns presented in this article remains interpretive and does not stem from statistical contrast testing. Network segregation as a predominant obstacle aligns with De Sousa Santos's (2011) concepts regarding the "waste of social experience," which occurs when women's lived experiences are minimized or unacknowledged within institutions. This finding is consistent with the "leaky pipeline" phenomenon reported by the World Economic Forum (2021) and the explanation of a "vicious cycle" driven by limited access to specialized mentorship and contacts (Szenkman & Lotitto, 2020; Noonan, 2017).

The finding that engineering and mathematics lead to higher levels of perceived barriers aligns with global data from the World Economic Forum (2021) and UNESCO (2020), which indicate that while health and natural sciences have made progress toward gender parity, ICT and engineering fields continue to exhibit marked female underrepresentation. This pattern can be understood through Foucault's (1975/2002) concept of the "microphysics of power," wherein institutions function as disciplinary mechanisms. The low scores for epistemological insecurity mirror those reported by Hernández Herrera and Hernández Herrera (2023), who identified low levels of epistemological insecurity accompanied by a strong sense of achievement among female graduates from federal technological institutes. This consistency aligns with observations by Carrillo Espadas and Flores Galaz (2023), who demonstrated that women who persevere along scientific tracks in Yucatán develop a form of resilience that serves as a "protective shield." However, this finding diverges from Master et al. (2021), who argue that stereotypes regarding internal ability represent the primary driver of inequalities; this discrepancy suggests that in southeastern Mexico, the core issue may not stem from a lack of self-efficacy, but rather from external and cognitive obstacles that—as Bachelard (1938/2000) cautions—become embedded within the institutional environment. Gender stereotypes remain persistent across all fields, underscoring their structural and pervasive nature (Camacho et al., 2021; Canales et al., 2022; Gundur & Suresh Kumar, 2025) and echoing the warnings of Silbiger and Stubler (2019) regarding biases in professional validation processes. Furthermore, the fact that employed female students exhibit slightly higher perception levels is consistent with Morales-Brito and Rojas-Cabezas (2021), ESADE reports (2021), and Caputo, Vargas, and Requena (2016), all of which indicate that obstacles do not diminish upon degree completion, but rather shift into barriers to career retention and advancement.

Conclusions

According to the participants' perspective, the gender gap in STEM is not merely a numerical problem, but rather a systemic configuration of barriers that hinders the development of scientific thinking. Network exclusion emerges as the epistemological obstacle perceived with the greatest relative intensity across all disciplines, highlighting the vital importance of interactions governing access, participation, and presence within academic and professional environments.

Although gender stereotypes are not the primary obstacle, they remain consistently present, underscoring their structural and pervasive nature, whereas epistemological insecurity surfaces as the least perceptible dimension. Employment status appears to accentuate or make certain difficulties more evident; however, given the descriptive nature of the study design, this does not imply a causal relationship.

Limitations and future lines of research. This study presents limitations that, rather than diminishing the findings, serve to guide future research directions: (1) sampling was restricted to two higher education institutions in southern Yucatán, meaning the results cannot be generalized; (2) the self-reported nature of the instrument may introduce social desirability bias; and (3) the descriptive scope precludes establishing causal relationships. Consequently, future studies should replicate this research using larger and more balanced samples, incorporate inferential analysis and variability measures, report reliability metrics per dimension, and enrich the methodological approach through qualitative frameworks capable of capturing less visible aspects of women's experiences in STEM.

Ultimately, this study provides initial empirical evidence pointing to the need for instruments that encompass both the structural and epistemological dimensions of gender disparity in STEM. By centering the lived experiences of women in southeastern Mexico, more responsive and inclusive educational systems can be systematically built.

Author Contributions

Rennata González Ruíz: Conceptualization, methodology, formal analysis, writing – original draft, writing – review & editing.

J. Gabriel Domínguez Castillo: Conceptualization, methodology, formal analysis, writing – original draft, writing – review & editing.

Edit Romero Pavía: Data curation, formal analysis, writing – original draft, writing – review & editing.

Margarita Bakieva-Karimov: Data curation, formal analysis, writing – original draft, writing – review & editing.

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