Voices of Hope: A Phenomenological Study on Women's Self-Efficacy in Computer Engineering

Dr. Andrea Ramirez-Salgado, University of Florida

Andrea Ramirez-Salgado is an Instructional Assistant Professor in Engineering Education at the University of Florida, where she teaches courses in artificial intelligence and data science. Her research examines how instructional practices shape students' identities in engineering and computer science, and how these identities affect their career goals and persistence. She is particularly committed to creating inclusive, engaging learning environments that support diverse learners.

Dr. Pavlo Antonenko

Pavlo "Pasha" Antonenko is an Associate Professor of Educational Technology at the University of Florida. His interests focus on the design of technology-enhanced learning environments and rigorous mixed-method research on the effective conditions for tec

Dr. Swarup Bhunia
Christine Wusylko, University of Florida

Christine a postdoctoral fellow at the University of Florida. She draws on over 10 years of experience teaching science and technology across grade levels K-16, to produce useful and usable knowledge, which is both driven by problems of practice and is theoretically grounded. Her research and development program is centered on helping young people develop AI and STEM literacy in authentic learning environments.

Woorin Hwang, University of Florida

Woorin Hwang is a Ph.D. candidate at the School of Teaching and Learning at the University of Florida. Her research is focused on assisting learners' career choices by integrating Artificial Intelligence (AI) in teaching and learning, with ongoing projects related to AI literacy, Edge AI, and recommender system in engineering education. Prior to joining the University of Florida, she worked as a teacher and instructional designer in South Korea.

Ms. Yessy Eka Ambarwati, University of Florida

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Full Research Paper

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Introduction

The underrepresentation of women in computer engineering (CE) is not just a disparity but a symptom of deeper systemic issues that the field has struggled to address for decades. Despite numerous initiatives, the factors discouraging women from entering and persisting in this domain—such as cultural biases, gender stereotypes, and a lack of relevant role models—remain deeply entrenched. These barriers hinder innovation and reduce the diversity of thought needed to tackle today's complex technological challenges. While efforts such as mentorship programs and diversity campaigns have been introduced, progress remains frustratingly slow. To create lasting change, it is clear that we need to develop a deeper understanding of the experiences and support systems that enable women to thrive in CE.

This study sought to address the ongoing gender gap in CE by examining the essence of the lived experiences of four women during their first year in a CE program, with a focus on the sources of their self-efficacy. Self-efficacy is an essential construct in understanding women's success in CE, as it directly affects their motivation, resilience, and performance. Drawing from Bandura's theory [1], self-efficacy is shaped by four main sources: a) mastery experiences that build confidence through achievements, b) vicarious experiences that strengthen confidence by observing others' success, c) social persuasion, such as encouragement from mentors or peers, and d) physiological and emotional states, which influence how individuals interpret their emotions in challenging situations. Conducted at a large R1 public institution in the southeastern U.S., this study examined women enrolled in an equity-centered introductory embedded systems course. Using transcendental phenomenology and identity mapping techniques, it explored their experiences through in-depth interviews conducted at two critical points: the end of their first semester, when they had recently completed the course, and again three months later. This time-spanning approach allowed for a deeper exploration of how their self-efficacy evolved over time, revealing key insights into the factors that influenced their persistence in CE.

The course was designed as a project-based learning experience, empowering students to build self-efficacy by engaging in hands-on work with embedded systems to solve real-world challenges. The findings reveal a nuanced relationship between various factors that both supported and challenged the women's confidence. Overcoming technical challenges and excelling in their projects provided essential mastery experiences that built resilience. However, while observing women role models offered vicarious learning benefits, societal biases frequently undermined this positive impact. Social persuasion, particularly from supportive mentors and peers, was crucial in fostering a belief in their capabilities, though interactions with

men peers sometimes eroded this confidence. Physiological and emotional states, including stress and anxiety, added another layer of difficulty, yet moments of recognition emerged as the women began to see their unique contributions within a men-dominated space. This study underscores the urgent need for more inclusive environments and strategies that nurture women's self-efficacy, emphasizing the importance of systems that counteract negative influences. These insights are key to empowering women in CE to persist, innovate, and lead in a field that needs their contributions.

Keywords: AIoT education, self-efficacy, CE career intention, transcendental phenomenology, hands-on learning.

Purpose

This study was conducted within a first-year, equity-centered embedded systems CE course (i.e., the equity-centered CE course) taught by a researcher in this study who is experienced in CE and a role model for the students. Grounded in transcendental phenomenology, the study aimed to systematically explore the lived experiences of first-year women engineering students. It focused on their self-efficacy and career intentions in CE and how these aspirations evolved during their first semester in the equity-centered course and into their second semester. The following question guided the research:

How do first-year engineering students who identify as or affiliate with women describe their experiences related to CE self-efficacy and career intention before, during, and after an equity-centered CE course?

Theoretical Background

This study is grounded in self-efficacy theory, a central predictor of career intention in STEM with high self-efficacy linked to greater persistence and resilience in a field [2], [3]. Self-efficacy refers to individuals' belief in their ability to succeed in specific tasks, shaping motivation, persistence, and resilience. Bandura [2] identified four sources of self-efficacy:

1. Mastery Experiences – Personal success that builds confidence.
2. Vicarious Experiences – Observing similar others succeed.
3. Social Persuasion – Encouragement from peers and mentors.
4. Physiological and Emotional States – Emotional well-being impacting confidence.

In STEM fields like CE, self-efficacy directly influences students' persistence and career intentions [3]. For women, often underrepresented in CE, these beliefs are shaped by educational environments and societal factors, making inclusive and supportive learning contexts critical [4].

Self-Efficacy, Persistence, and Support Systems

Higher self-efficacy is strongly linked to greater persistence in STEM [5]. Support systems—mentoring, positive peer networks, and exposure to female role models—play a vital role in enhancing self-efficacy and sustaining engagement [6]. Inclusive educational environments act as protective factors that buffer against gender bias and isolation [7].

Resilience Processes in STEM

To further explain how women navigate challenges in CE, this study incorporates [8] resilience framework, which includes:

1. Vulnerability Factors – Personal and social challenges (e.g., stereotype threat).
2. Risk Factors – Systemic barriers (e.g., gender bias, and sexist workplace culture).
3. Protective Factors – Supportive mentors and inclusive environments.
4. Compensatory Strategies – Proactive coping mechanisms (e.g., seeking support).

By integrating self-efficacy theory and resilience processes, this study offers a comprehensive perspective on how first-year women engineering students develop and maintain positive self-efficacy and career intention in CE. This framework guided the study from design to analysis, offering both a conceptual foundation and an analytical lens. It foregrounds the dynamic interaction between students' internal belief systems—particularly their perceived competence in engineering-related tasks—and the external supports available to them, such as instructional strategies, mentoring, and affirming peer networks. As an analytical tool, the framework enabled a systematic examination of how various sources of self-efficacy intersect with resilience processes to shape students' persistence and sense of belonging in CE.

Methods

Research Design

This qualitative study utilizes a transcendental phenomenological approach to deeply explore participants' lived experiences [9]. Rooted in Husserl's [10] philosophy and expanded by Moustakas [11], this method systematically examines how individuals perceive and interpret their experiences. Moustakas [11] defines transcendental phenomenology as "a scientific [descriptive] study of the appearance of things, of phenomena just as we see them and as they appear to us in consciousness" (p. 49). This approach enables a detailed understanding of the conscious processes influencing career intentions.

Central to this method are the concepts of intentionality, noema, and noesis. Intentionality refers to how mental acts are purposefully directed toward objects [11]. Specifically, noema is the

"what" of an experience—the phenomenon itself—while noesis is the "how," or the interpretive process through which the experience is understood. Their interaction forms the foundation of conscious experience and is essential for constructing textural (noema) and structural (noesis) descriptions in phenomenological analysis.

Methodological steps such as epoché, phenomenological reduction, imaginative variation, and synthesis of meaning guide the analysis, allowing for a rich and unbiased understanding of participants' experiences.

Researcher Positionality

While this study was conducted by a team of researchers, the decision to adopt a transcendental phenomenological approach was primarily shaped by the lead researcher's positionality. As a woman who grew up in Colombia immersed in her family's civil engineering company, she developed an early sense of belonging in engineering—an outlook later complicated by experiences of gendered bias during her studies in computer science. These personal and academic journeys, coupled with her ongoing work in engineering education, have informed her deep interest in understanding how women navigate identity, confidence, and persistence in men-dominated fields like CE. This background made transcendental phenomenology an especially fitting approach, as it offers a rigorous, reflective method for accessing and interpreting participants' lived experiences in a way that centers their own meaning-making while striving to bracket prior assumptions.

Instructional Approach

The curriculum developed for this study focuses on embedded systems, specialized computer systems designed for specific functions within larger devices, integrating software and hardware components [12], [13]. It aims to attract students interested in software by offering practical applications of algorithms and programming languages in real-world contexts. For those inclined towards hardware, the curriculum provides hands-on experience in designing, implementing, and troubleshooting hardware systems. The equity-centered CE course was intentionally designed not only to teach technical skills but also to actively support the development of self-efficacy. Grounded in principles of Universal Design for Learning (UDL) [14] and Culturally Responsive Pedagogies (CRP) [15] the instructional approach integrated inclusive and equity-focused practices to address the diverse cognitive, cultural, and experiential needs of students. UDL promotes flexible teaching and learning strategies that accommodate different learning preferences and abilities, while CRP emphasizes validating and incorporating students' cultural knowledge, experiences, and identities into the learning environment.

Study Context and Participants

According to Moustakas [11], participant selection in transcendental phenomenology prioritizes individuals who have experienced the phenomenon, are deeply interested in understanding its nature and meanings, and are willing to participate in a lengthy interview and possibly a follow-up interview. Therefore, all women enrolled in the equity-centered CE course were invited to participate in this study. Out of the 22 students in the course (16 men and 6 women), four women provided informed consent.

Measures and Data Sources

The primary data for this study was collected qualitatively through in-depth, informal, and interactive interviews [11]. Interviews took place at the end of the semester and again three months later. During each interview, participants created identity maps—diagrams expressing their mental interpretations of the discussed topics—following the approach by Futch and Fine [16], who have extensively used identity maps to capture and visualize personal experiences. Before each interview, the researcher engaged in the epoché process to foster an open and unbiased atmosphere. This involved consciously acknowledging and setting aside biases, preconceptions, and assumptions about the phenomenon to ensure they did not influence the interview [11]. Additionally, the researcher conducted observations during each class, maintaining an observation journal to document general struggles, situations, relationships, social interactions, and comments made by students.

Data Analysis

The data analysis process, illustrated in Fig. 1 and guided by Moustakas [11], used noematic and noetic processes to understand intentionality. The steps included phenomenological reduction, imaginative variation, and synthesis of findings. For phenomenological reduction, the researcher recorded and transcribed interviews, extracting horizons and transforming them into invariant constituents categorized into periods before, during, and after the CE course. These were clustered into meaning units to create individual and composite textural (noematic) descriptions, focusing on the "what" of the experience. Imaginative variation involved considering variations in time, space, causality, materiality, and relationships to uncover the "how" of the experience. These structural qualities were captured in composite structural descriptions. The researcher combined textural and structural descriptions into themes, integrating the "what" (noema) and the "how" (noesis) of the experiences. These themes were grouped into core essences, creating a cohesive synthesis of findings that all relate to the sources of self-efficacy.

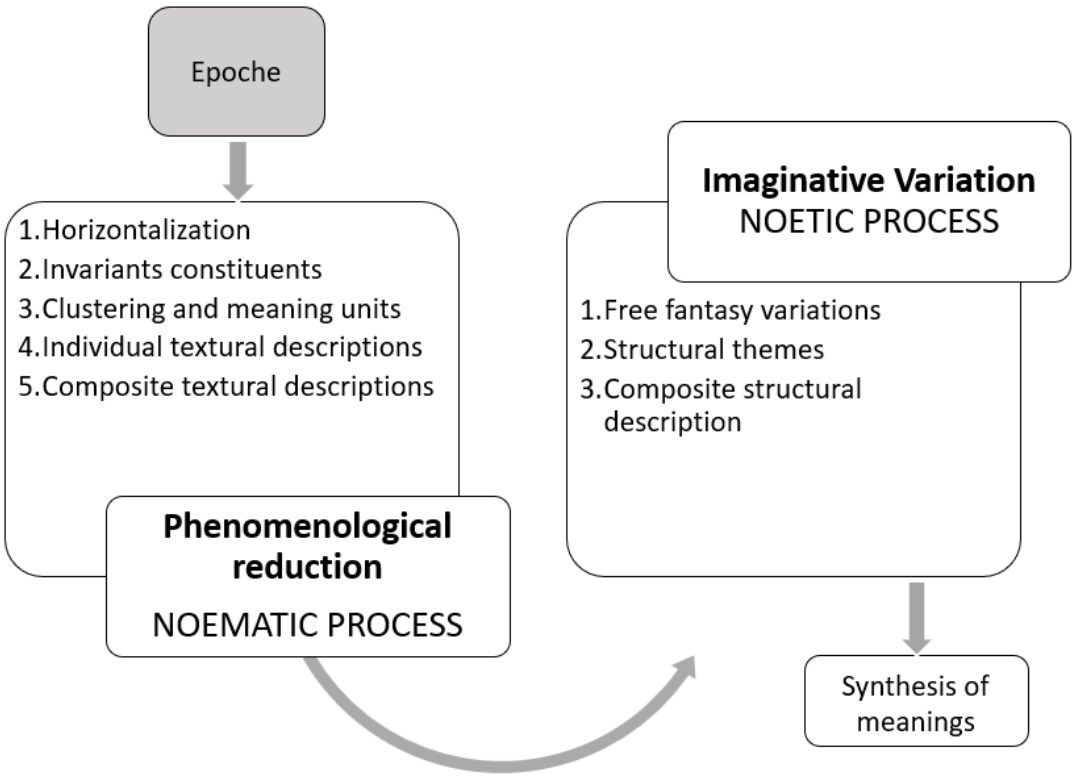

Figure 1. Data Analysis Process Based on Transcendental Phenomenology

Results and Discussion

Mastery Experiences

Mastery experiences, the most influential source of self-efficacy, were pivotal in shaping the participants' confidence and resilience in engineering fields. Their journey began with the sense of accomplishment gained through college admissions, initially perceived as a significant personal achievement. However, this was quickly challenged by the realities of navigating a men-dominated field. The participants faced derogatory comments, stereotypes, and other barriers, yet their determination to overcome these obstacles reinforced their belief in their abilities [4]. As one participant noted, "*If other people doubt me in my field because I'm a woman, I feel like a light of fire, so it encourages me to do better.*" These experiences, though fraught with stress and doubt, became milestones of personal growth [17], [18].

In addition, self-initiated learning in Python programming and DIY electronics projects became critical mastery experiences. Teaching others to code and dismantling electronics provided hands-on, practical engagement that bolstered confidence. Early exposure to engineering concepts in K-12 education further amplified their interest and competence [19], [20] . Success in academic achievements, such as winning project competitions and receiving awards, served as

validation of their abilities. One participant shared, *"I honestly thought [my peers] did better, but our project's applicability was more impactful, and winning made me feel really accomplished."* These cumulative experiences solidified their self-efficacy and professional identity, proving that persistence and effort could lead to significant outcomes [3].

Vicarious Experiences

Vicarious experiences, gained by observing others succeed, played a crucial role in enhancing participants' self-efficacy. The presence of women instructors and peers provided powerful examples of success in men-dominated environments, though these positive influences were sometimes undermined by inequitable treatment [21]. One participant recounted, *"Seeing him ask me a question and then immediately turn to a male co-instructor was undermining"* Despite such incidents, these women drew inspiration from visible role models, emphasizing the need for increasing the authority and visibility of women in engineering roles [6].

Exposure to professionals in general engineering courses and tutoring sessions helped participants explore diverse career paths. Observing others in programming and semiconductor manufacturing allowed them to compare their interests and disinterests [21]. As one participant noted, *"I thought everything was interesting, but I don't see myself doing this as a career"*. Mentors from high-achieving organizations also inspired participants to pursue greater opportunities*. "My mentor works at Microsoft, and her mentor is at Google. Being surrounded by them encouraged me to push further,"* shared one participant, illustrating the significant influence of mentorship [22]. Collectively, these experiences underscored the importance of providing visible and relatable role models to inspire confidence and ambition.

Social Persuasion

Social persuasion, encompassing encouragement and feedback from others, provided a blend of support and challenges that shaped the participants' self-efficacy. Supportive communities, such as women-centered organizations and engineering clubs, offered a sense of belonging and motivation [23]. One participant remarked*, "We have conventions mainly for women and nonbinary engineers. I think it's slowly getting better."* Positive reinforcement from instructors and peers further validated their abilities [2]. Teaching coding, for instance, became a source of satisfaction and confidence, with one participant sharing*, "Teaching others Python gave me satisfaction and made me consider careers involving that"*

However, participants also encountered negative forms of social persuasion, including subtle biases and skeptical remarks that undermined their sense of belonging in engineering [24], [25]. As one participant recalled, "*He was just annoying and turned around one day to ask why I was taking notes. It's definitely a stereotype*." This interaction illustrates how even seemingly minor comments can reinforce gendered assumptions and contribute to a hostile learning environment. Despite these discouraging experiences, many participants also described receiving affirming

messages from family members, instructors, and mentors—sources of encouragement that often counterbalanced negativity and reinforced their commitment to persist [26]. This tension between discouraging and affirming social cues underscores the nuanced, bidirectional influence of social persuasion on students' confidence and motivation.

Physiological and Emotional States

Physiological and emotional states profoundly influenced participants' self-efficacy by shaping how they interpreted their experiences. Stress and anxiety were common, particularly in men-dominated environments where isolation and unequal treatment heightened discomfort [20], [22]. One participant shared, *"When I walk into the lab, I'm the only woman. It's overwhelming but gives me a sense of purpose because I'm here, and I made it."* These emotions created a dual impact: while stress sometimes eroded confidence, the sense of empowerment derived from overcoming challenges reinforced resilience.

Participants also faced emotional strain during programming projects [25], with one expressing, *"Every time I would code, I thought the result was cool, but I hated the process."* These experiences occasionally led to shifts in academic focus, as participants sought fields that aligned better with their interests and emotional well-being. Balancing academic and social lives was another challenge, but extracurricular activities provided a necessary outlet [17]. *"This semester, I focused on extracurriculars, which helped balance my experience,"* noted one participant. Emotional resilience, combined with supportive environments, proved essential in maintaining self-efficacy, highlighting the importance of addressing emotional well-being in educational settings.

Implications for Practice

This study highlights the effectiveness of equity-centered, inclusive curricula in supporting women's engagement in CE through collaborative, project-based learning. Hands-on experiences combining software and hardware to solve meaningful problems fostered participants' confidence and self-efficacy, aligning with their desire to help others: *"I like to see that what I'm building or what I'm making is helping people."*

Compared to traditional lecture-based courses, the equity-centered CE offered a supportive environment where women received encouragement from peers and female instructors. This support helped them navigate gender bias and gain recognition for their innovative work: *" This class is way more hands-on than any other class I have... This one was much more appealing because I was able to work on things that really interested me."*

The study's time-spanning design—tracking participants before, during, and after the course—revealed how women developed resilience over time. Following Kitano and Lewis [8] resilience framework, participants experienced vulnerability in challenging situations: *"All these guys know*

how to do it." They also faced risk factors like negative peer influence: *"If they're not into it and they're miserable, then maybe that's a sign."*

Protective factors, such as external validation, bolstered resilience: *"They consider me to be an engineer too."* Additionally, compensatory strategies like setting high academic goals led to increased confidence: *"I got all A's... I am an engineer."*

In conclusion, equity-centered, hands-on curricula are vital for fostering self-efficacy and career motivation among women in CE. The study's long-term perspective offers valuable insights into the resilience processes necessary for women's success in the field [8].

Limitations and Future Steps

The study is delimited by its qualitative design and the specific context of the equity-centered CE course. As such, the findings are not intended to be generalizable to all first-year engineering students or to other educational contexts. The small, purposively selected sample offers in-depth insight but may not capture the full diversity of experiences among first-year women in CE. While self-efficacy serves as a central framework for exploring how students assess their ability to succeed in engineering contexts, it has been critiqued for its limited attention to the structural and sociocultural barriers that often shape the experiences of minoritized populations [27], [28]. This is particularly relevant in men-dominated fields such as CE, where systemic inequities can influence both identity development and persistence in ways that self-efficacy alone may not fully explain. Although outcome expectations—students' beliefs about the potential consequences of pursuing specific educational and career paths—are not examined in the present study, they represent an important direction for the researcher's broader agenda [29].

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