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Technical and Vocational Education and Training College Female Students' Experiences in Engineering Disciplines

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Abstract

The underrepresentation of women in engineering impedes the achievement of gender equity within the South African technical workforce. The engineering profession is integral to national economic and industrial development; however, structural and socio-cultural inequities are exacerbated due to gender imbalances. This study employs Schlossberg's Transition Theory as an analytical framework to examine how female students navigate their educational journeys within traditionally male-dominated engineering programmes. The research question that guided this qualitative study was: What are the lived experiences of female students enrolled in engineering programmes at the Technical and Vocational Education and Training (TVET) college in South Africa? Open-ended questionnaires, focus group interviews, individual interviews, and collages were used to collect data from twenty-one purposively selected female engineering students. On the one hand, the findings highlight the influence of entrenched cultural norms, scarcity of female role models, institutional biases, and limited gender-responsive pedagogies. On the other hand, it documents the resilience strategies female students employ to navigate and persist within male-dominated learning spaces. The findings signal contextually relevant information for reforming engineering education at the TVET level, such as embracing inclusive teaching methods, establishing focused support systems, and cultivating supportive environments that promote belonging and achievement These findings undergird future conversations on gender equality in science, technology, engineering, and mathematics (STEM) and support national goals like the National Development Plan, aimed at increasing and diversifying South Africa's engineering capabilities.

1. Introduction

Engineering is central to South Africa's socio-economic development as it supports key infrastructure, energy, and technology sectors. However, the country faces a significant engineering skills shortage estimated at 40% below labour market demand, which poses a barrier to achieving the goals of the National Development Plan (Kanga, 2021; Kana & Letaba, 2024). In response to the skills shortages in the engineering sector, Technical and Vocational Education and Training (TVET) colleges have been positioned as key sites for skills development, offering accessible, practice-oriented education to diverse student populations (Terblanche & Waghid, 2023).

Despite their strategic role, TVET colleges continue to reflect and reproduce gender disparities that are evident in engineering. Women remain underrepresented in engineering globally, comprising less than 30% of the profession (UNESCO, 2022). In South Africa, the situation is even more pronounced, with only 13% of registered engineers being women (Sikhosana et al., 2023). These disparities are rooted in historical inequalities, gendered social norms, and institutional practices that limit women's access, participation, and progression, especially those from historically disadvantaged backgrounds (Idahosa & Mkhize, 2021; Mhlanga, 2024).

While initiatives such as scholarships, outreach programmes, and institutional reforms have improved enrolment figures at some universities, TVET colleges continue to face challenges, including gender-insensitive pedagogy, limited female role models, and unsupportive learning environments (Govender & Mbatha, 2023; Blake & Mavuso, 2024). Moreover, foundational gaps in STEM education, biased career guidance, and experiences of discrimination often deter female students from pursuing and persisting in engineering (Nxumalo & Peterson, 2022). While considerable attention has been given to gender equity in university-level STEM education, there remains a paucity of research focused specifically on female students in TVET engineering programmes. Moreover, although policy and advocacy efforts such as the WISET (women in science, engineering and technology) programme have promoted gender inclusivity in STEM, there remains a notable gap in research on female students' experiences within the TVET engineering context (Mahlangu & Tshabalala, 2022). This study addresses this gap by exploring the experiences of female students in different engineering disciplines at a selected TVET college in South Africa. In doing so, it responds directly to the NDP's call for a more inclusive, diverse, and skilled workforce. It contributes to the growing body of literature focused on gender equity in STEM education. The central research question guiding this study is: What are the lived experiences of female students transitioning into and through TVET engineering programmes in South Africa? To address this research question, the study pursues the following specific objectives:

- To explore the motivations and factors influencing female students' decisions to enroll in TVET engineering programmes
- To examine the academic and social experiences of female students during their transition into engineering education
- To identify challenges and support systems that impact female students' persistence in TVET engineering programmes

2. Literature Review

This literature review examines key themes emerging from the body of research on female participation in engineering programs at TVET colleges.

Research indicates that women are significantly underrepresented in engineering fields globally. According to UNESCO (2018), women comprise about 28% of engineering graduates worldwide. Within sub-Saharan Africa, the figure is approximately 15% (World Economic Forum, 2023). Despite sustained interventions, the pace of change remains slow, particularly in developing nations where structural and cultural barriers are deeply entrenched (Dasgupta & Stout, 2014). These global trends are mirrored in South Africa, where women comprise less than 20% of engineering students in TVET institutions (DHET, 2020), despite making up approximately 55% of the overall TVET population (Statistics South Africa, 2022). This indicates a gendered concentration within programs, with women more likely to enroll in traditionally feminised fields such as education and health sciences. Policy responses, and the National Skills Development Plan 2030, have sought to address these disparities but face challenges in implementation (Department of Higher Education and Training, 2023).

TVET colleges are often plagued by limited resources, outdated equipment, and inadequate infrastructure, which disproportionately affects female students. The absence of gender-sensitive policies, female instructors, and mentorship structures further undermines inclusivity (Bray-Collins et al., 2022). Gender biases perpetuated by curriculum content and teaching strategies used do not resonate with learner diversity and further alienate female students (Tikly et al., 2023).

Cultural norms that associate engineering with masculinity continue to influence young women's career choices. For example, family expectations, community perceptions, and internalised gender stereotypes deter many capable students from pursuing technical education (Maila & Matjila, 2022). Economic constraints also play a significant role, with tuition, transportation, and material costs creating financial barriers that are often insurmountable for low-income students (Nzimande & Mathekga, 2023). Despite the challenges, several initiatives have emerged to support female engineering students. These include industry-sponsored scholarships, mentorship programmes, and student-led associations that offer peer support and professional development opportunities (Khumalo & Bhengu, 2023). Pedagogical reforms such as project-based learning and collaborative instruction have also improved engagement and retention among female students (Coetzee et al., 2022).

Research specifically examining why females opt out of engineering reveals multiple intersecting factors. Stereotype threat - the fear of confirming negative stereotypes about one's group - significantly influences young women's decisions to avoid engineering fields (Spencer et al., 2016). When girls internalise societal messages that

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engineering is a masculine domain, they often pre-emptively self-select out of these pathways regardless of their actual abilities (Master & Meltzoff, 2020). Early educational experiences play a decisive role. Miller et al. (2018) found that by age 6, girls begin to associate brilliance with males, leading them to avoid activities believed to require exceptional intellectual ability - a category that includes engineering. This is compounded by classroom dynamics where teachers unconsciously provide more encouragement and feedback to male students in STEM subjects (Riegle-Crumb & Morton, 2017). The absence of visible female engineers in media, textbooks, and professional networks creates what researchers term a "role model gap" (Cheryan et al., 2017). Young women struggle to envision themselves in careers where they rarely see people who look like them succeeding. This visualisation gap is particularly pronounced in sub-Saharan Africa, where engineering remains heavily male-dominated (Etzkowitz et al., 2020).

Family influence cannot be understated. Parents' gendered beliefs about their children's abilities, often unconscious, shape educational trajectories from early childhood (Tomasetto et al., 2015). Mothers and fathers consistently rate sons as more capable in mathematics than daughters with identical performance, leading to differential encouragement toward technical fields (Gunderson et al., 2012). Finally, anticipated workplace discrimination and concerns about work-life balance deter capable women from pursuing engineering. Research shows that young women anticipate hostile or unwelcoming workplace cultures in engineering and make rational decisions to pursue careers in fields perceived as more inclusive (Fouad et al., 2017). These anticipatory concerns are validated by high attrition rates among women who do enter engineering, with many leaving due to workplace climate issues rather than lack of interest or ability (Morganson et al., 2021).

3. Theoretical Framework

This study draws on Schlossberg's Transition Theory (1981) to examine how female students navigate their educational journeys within engineering programmes at South African TVET colleges.

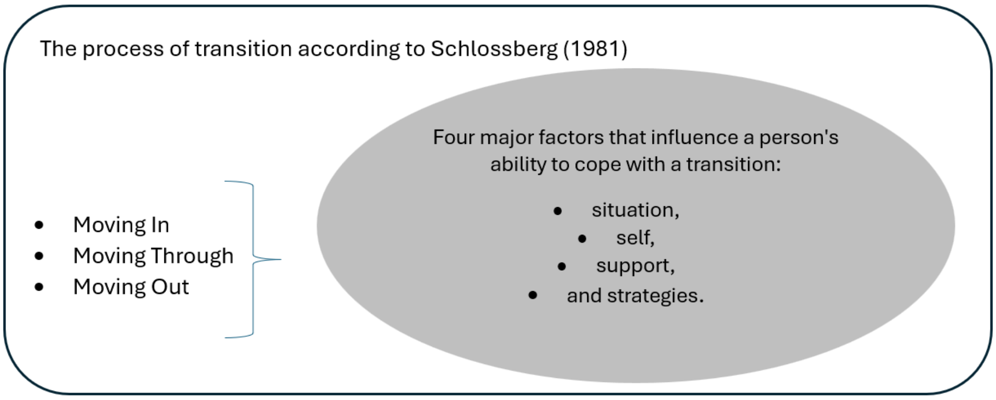

Fig. 1 *The process of transition according to Schlossberg (1981)*

The theory conceptualises transitions as significant life events or non-events that require psychological, social, and behavioural adjustment. It highlights how individuals "move in," "move through," and "move out" of transitional experiences, shaped by four interrelated dimensions: Situation, Self, Support, and Strategies (Schlossberg, 1981)

TVET students, particularly women in engineering, often experience complex transitions related to academic challenges, identity shifts, and socio-economic constraints (Killam & Degges-White, 2017). These experiences are further nuanced by intersectional identities such as race, class, and gender (Crenshaw, 1989). For instance, African women in engineering programmes may simultaneously face racism, sexism, and economic marginalisation, compounding their transitional difficulties (Blosser, 2020; Makhubela & Ntswane, 2022).

Contextual elements, such as insufficient school resources, minimal career counseling, and family obligations, affect students' capacity to participate in and remain in engineering education. Transitions frequently disturb established roles, routines, and relationships, necessitating students to embrace new identities and coping mechanisms while preserving or redefining previous ones (Akala & Divala, 2022).

The Four S's framework plays a crucial role in recognising facilitators and obstacles in students' transitions:

- Circumstance: Timing, educational requirements, and life pressures (Matenda, 2020).
- Self: Resilience, self-confidence, and past experiences (Moletsane & Reddy, 2011).
- Support: Peer networks, mentorship, and institutional resources (Jansen et al, 2019).
- Strategies: Coping tools such as time management, study groups, and self-advocacy (Baloyi & Makhanya, 2021).

Although underutilized in engineering education, Schlossberg's model offers a robust lens for analysing female students' lived realities at TVET colleges (Magubane, 2023). It not only accounts for structural and interpersonal factors but also foregrounds student agency and adaptation. This framework thus enables a deeper understanding of how institutional practices can be reshaped to improve retention, inclusivity, and academic success for women in engineering.

4. Methodology

This qualitative research was situated within an interpretive framework. The interpretive paradigm is ideal for this study, as it facilitates a thorough exploration of participants' viewpoints, beliefs, and the significance they associate with their educational experiences.

4.1 Location of the Study

This study was conducted at Cool-West TVET College in the Gauteng province. There are two campuses (A and B). Campus A offers three engineering streams, namely R191 Mechanical Engineering N1 to N3, Electrical Engineering N1 to N6 and National Certificate (Vocational) Electrical Infrastructure Construction L2 to L4 and campus B offers four streams R191 Electrical Engineering N1 to N3, Mechanical Engineering N1 to N6, National Certificate (Vocational) Engineering Related Design L2 to L4 majoring in Welding and National Certificate (Vocational) Engineering Related Design L2 to L4 majoring in Automotive Repair and Maintenance.

4.2 Sampling

This study employed a case study design to explore the experiences of female students in engineering disciplines at a selected TVET college. The case in this study involves a female student in engineering disciplines, and the context is a TVET college. Guided by the case study approach, participants were purposively selected to provide rich, in-depth insights into the phenomenon within this specific institutional context. Purposive sampling is a deliberate process of selecting participants based on their specific attributes. For this study, participants had to be female students enrolled in an engineering program at Cool West TVET College. Campus A offers three engineering streams; three students per stream were selected (3 × 3 = 9 students) for Campus B, which offers four engineering streams; three students per stream were selected (4 × 3 = 12 students). A total of 21 female engineering students were selected to participate in this study. Participants were assigned pseudonyms ranging from PI to P21.

Table 1 *Distribution of participants according to their programmes of study*

Engineering programme	Participants on campus A	Participant on campus B
Prevocational learning programme (PLP)	1, 2,	
Engineering Related Design L2		11
Engineering Related Design L3		12
Engineering Related Design L4		13
Electrical Infrastructure Construction L2	3, 4, 5	
Mechanical Engineering Fitting and Machining N2	6	14
Mechanical Engineering N3	7	
Mechanical Engineering – Diesel Mechanic N2		15
Electrical Engineering N1		16
Electrical Engineering N2		17
Electrical Engineering N2		18
Electrical Engineering N4	8	19
Electrical Engineering N5	9	20
Electrical Engineering N6	10	21

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4.3 Data Collection Instruments

Data were generated through multiple methods to enable triangulation and enhance trustworthiness.

4.3.1 Open-Ended Questionnaire

An 11-item open-ended questionnaire was administered first to explore participants' initial motivations and experiences. Questions were structured around Schlossberg's (1981) "moving in" phase and included to explore the following question: What influenced your decision to enrol in engineering at this TVET college? Describe your expectations before starting the programme. What challenges did you anticipate facing as a female student in engineering? Who supported your decision to pursue engineering education? The questionnaire was piloted with three female engineering students not included in the main study to ensure clarity and appropriateness.

4.3.2 Focus Group Interviews

Two focus group interviews were conducted (one per campus), each lasting 60-90 minutes with 8-12 participants. The semi-structured interview guide was designed using Schlossberg's transition phases and the Four S's framework. Sample questions included:

Moving Through Phase: How would you describe your learning experiences in practical sessions compared to theory classes? Can you share specific instances where you felt included or excluded in your engineering programme?

Four S's Framework: Situation: What specific academic or personal circumstances have most significantly impacted your engineering studies? Self: How has your confidence in your engineering abilities changed since starting the programme? Support: Who or what has been most helpful in supporting your persistence in engineering? Strategies: What specific approaches have you used to overcome challenges in your programme?

All focus groups were audio-recorded with permission and facilitated by the first author, with a research assistant taking field notes.

4.3.3 Individual Interviews

Following focus groups, 8 participants (selected for diversity of experiences and programmes) engaged in individual semi-structured interviews lasting 30-45 minutes. These interviews allowed deeper exploration of sensitive topics and personal experiences that participants might not have shared in group settings.

4.3.4 Collage-Making

Collages provided a visual and reflective method for participants to express experiences that were not easily captured through verbal means (Masinga et al., 2016). Participants received: A4 poster boards, Magazines, colored paper, markers, scissors, glue, and written instructions: "Create a visual representation of your journey as a female engineering student. Include images, words, or symbols that represent your motivations, challenges, support systems, and aspirations."

Participants worked independently for 45-60 minutes, followed by post-collage individual interviews (15-20 minutes each) using interpretive questioning: Tell me about your collage. Where should I start looking? What does this image/word represent for you? Why did you choose these particular colors/symbols? What story does your collage tell about your engineering experience? These collages provided rich insights into participants' emotional and cognitive landscapes, revealing metaphors and meanings that complemented verbal data.

Audio recordings were transcribed verbatim and sent to the participant for member checking to ensure the data was accurately captured.

4.4 Data Analysis

Data were read repeatedly (within and across datasets) to note similarities and divergences before coding. Thus, the analysis was recursive, iterative, and progressive. Similar codes were regrouped into themes as reflected in Table 2 below. To enhance the validity and credibility of the findings, expert validation was conducted following the initial data analysis. Three experts were purposively selected based on their expertise: one gender studies specialist with a research focus on women in STEM education, one TVET curriculum specialist with over 15 years of experience in engineering education, and one senior female engineer working in industry who mentors TVET students. Experts were provided with anonymised transcripts, preliminary codes, and emerging themes. They independently reviewed the coding framework and thematic structure, providing written feedback on the appropriateness of the interpretations and the alignment between the raw data and the analytical conclusions. Their feedback was incorporated through the iterative refinement of themes and subcategories, thereby strengthening the trustworthiness of the findings.

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Table 2 *Codes and themes*

Theme	Subcategory	Codes
Theme 1: Positive Experience - Motivations for Choosing Engineering	Intrinsic Motivation & Personal Interest	Passion for engineering (f=17), Curiosity (f=14), Desire to solve problems (f=16), Interest in how things function (f=15), Personal drive (f=13)
	Influence of Role Models & Exposure	Influence of family members (f=9), School exposure to engineering (f=12), Supportive teachers (f=11), Prior exposure to STEM subjects (f=14)
	Desire for Economic Empowerment	Better job prospects (f=19), financial independence (f=18), Breaking cycles of poverty (f=11), Long-term stability (f=15), Upward mobility (f=12)
	Gender Identity and Empowerment	Proving stereotypes wrong (f=16); Role model (f=13); Challenging gender norms (f=14); Breaking barriers (f=15)
Theme 2: Challenges in Academic Experiences - Gender Bias and Resource Constraints	Gender Bias in Practical Instruction	Unequal attention in practical's (f=18), Marginalisation during hands-on activities (f=17), Lecturer bias (f=16), Passive participation by female students (f=14)
	Resource Limitations	Outdated equipment (f=20), Inadequate learning tools (f=19), Cost of materials (f=15), Practical skill gaps (f=13)
	Impact of Gender Bias on Learning	Need to prove competence (f=17), Bias as motivation (f=10), Professional identity tax (f=8), Stereotype threat(f=12)
	Balancing Responsibilities	Household duties (f=14), Academic workload stress (f=18), Time poverty (f=11), Competing devotions (f=9)

Note**:** n=21 participants; frequencies represent number of participants whose responses were coded under each category

5. Findings and Discussion

5.1 Positive Experience – Motivations for Choosing Engineering

5.1.1 Intrinsic Motivation and Personal Interest

Participants' pursuit of engineering stemmed primarily from intrinsic interest, with passion for engineering (f=17), desire to solve problems (f=16), and curiosity about how things work (f=15) as dominant motivators, manifesting as genuine fascination with engineering principles and natural inclination toward technical problem-solving predating formal education.

Passion for engineering sustained participants through academic challenges. Participant 7 articulated: "I've always been fascinated by how things work, ever since I was a child, taking apart my mother's radio. Engineering isn't just a career choice for me—it's something that genuinely excites me." This deep-seated interest formed the foundation of academic persistence.

Problem-solving emerged as central to motivation, reflecting an engineering mindset that views challenges as opportunities for innovation. Participant 12 explained: "What draws me to engineering is the ability to create solutions that can improve people's lives. I see problems in my community and I want to be part of developing the solutions." This orientation connected personal interests with broader social contributions.

Curiosity about mechanisms served as another powerful motivator. Participant 21 reflected: "I've always been the person asking 'why' and 'how does that work?' My curiosity isn't satisfied with surface-level explanations—I need to understand the mechanisms, the principles, the engineering behind everything I encounter. That curiosity is what led me to engineering and what keeps me motivated even when the coursework is difficult."

Personal drive (f=13) manifested as internal determination to succeed regardless of external circumstances. Participant 19 stated: "I'm self-motivated in a way that doesn't depend on constant encouragement from others. Even when I face setbacks or when people question whether I belong in engineering, my internal drive keeps me moving forward." This self-directed motivation provided resilience against discouragement and enabled persistence despite gender-based obstacles.

These findings align with studies by Dasgupta and Stout (2014), confirming that self-efficacy in problem-solving strongly predicts persistence in STEM fields.

5.1.2 Influence of Role Models and Exposure

Role models and early exposure significantly shaped career trajectories, with prior STEM exposure (f=14), school exposure to engineering (f=12), supportive teachers (f=11), and family influence (f=9) all contributing to participants' decisions. These external influences worked synergistically with intrinsic motivation, providing inspiration and practical pathways.

Prior STEM exposure created confidence, facilitating the transition into engineering. Participant 21 explained: "Doing well in mathematics and physical science throughout high school built my confidence that I could handle engineering. I wasn't intimidated by the technical content because I had already developed strong analytical skills. That prior exposure meant I entered university with a solid foundation rather than feeling overwhelmed from the start." This preparation significantly contributed to the formation of an engineering identity.

School exposure served as a critical formal introduction. Participant 16 recounted: "In Grade 11, our school brought in engineers to talk about their work and demonstrate some basic engineering principles. That was the first time I realised that engineering was something I could study and that it involved the kind of problem-solving I enjoyed. That school program literally changed the trajectory of my life." Such structured exposure proved particularly important for students from backgrounds where engineering was unfamiliar.

Supportive teachers nurtured engineering aspirations by recognising and encouraging technical aptitude. Participant 9 reflected: "My mathematics teacher in high school saw my potential and actively encouraged me to consider engineering. She would stay after school to help me with advanced problems, brought me information about university programs, and even connected me with a female engineer. Without her support and belief in my abilities, I might not have had the confidence to apply for engineering." Teacher encouragement proved particularly meaningful where families lacked familiarity with higher education.

Family influence proved particularly impactful. Participant 3 described: "My father is a civil engineer, and growing up, I would visit construction sites with him during school holidays. He never treated me differently because I was a girl—he explained the engineering principles, showed me blueprints, and encouraged my questions. Having a family member in engineering made it feel accessible to me." This familial exposure demystified engineering as a career option.

These findings align with research demonstrating that multiple factors—including early STEM exposure, structured school programs, supportive teachers, and family influence—collectively shape women's engineering career pathways (Šimunović & Babarović, 2020; Kuchynka et al., 2023). Prior STEM academic preparation contributes to the formation of an engineering identity, with early career exposure representing one of the most effective recruitment strategies for increasing the number of women in STEM fields (Liang et al., 2023).

5.1.3 Desire for Economic Empowerment

Economic considerations constituted a powerful motivation, with better job prospects (f=19) and financial independence (f=18) being most frequently cited, reflecting participants' recognition of engineering as a pathway to long-term stability (f=15), upward mobility (f=12), and breaking the cycle of poverty (f=11).

Financial independence represented not merely economic security but autonomy and self-determination. Participant 5 articulated: "*Growing up, I watched my mother struggle financially, always dependent on others for support. I decided early on that I would create a different life for myself—one where I could support myself and my future family without depending on anyone. Engineering offers that possibility because the salaries are good and the job market is relatively stable. Financial independence means freedom to make my own choices, to help my family, and to live with dignity*."

Better job prospects attracted participants who viewed engineering as offering strong employment opportunities. Participant 11 explained: "*In our current economic climate, having a qualification that leads to actual employment is critical. I researched career prospects extensively before choosing my degree, and engineering consistently showed high employment rates and good salary potential. Engineering isn't just a passion—it's a strategic career choice that will provide long-term job security*."

Long-term stability appealed to participants who valued security. Participant 14 reflected: "Engineering offers a career path with stability, which is incredibly important to me. Unlike some fields where employment is precarious or dependent on connections, engineering skills are consistently in demand. That stability means I can plan my life, perhaps buy a home eventually, support my parents as they age, and not constantly worry about where my next pay check will come from."

Breaking cycles of poverty (f=11) represented a transformative aspiration extending beyond individual achievement. Participant 18 shared: "*I come from a very poor background where no one in my family has ever had a professional career. Becoming an engineer means breaking a cycle of poverty that has trapped my family for generations. It's not just about me—it's about showing my younger siblings that education can transform your life. My success will open doors for them and change what's possible for our family*."

Upward mobility (f=12) captured participants' determination to improve their social and economic standing. Participant 20 stated: "*Engineering is my ticket to upward mobility—a way to move from working class to middle class, from economic struggle to financial comfort. Engineering provides a legitimate pathway for that kind of social mobility, which is why I'm willing to work so hard to succeed in this field.*"

These findings align with research demonstrating that financial independence and economic stability are among the most important motivating factors for highly educated women's career choices (Bezzina et al., 2013). Studies show that women consistently rate financial motivations as the most important, with a strong determination to achieve financial independence reflected across diverse contexts.

5.1.4 Gender Identity and Empowerment

Participants' motivations were deeply intertwined with their gender identity, with many explicitly articulating their pursuit of engineering as a challenge to gender norms (f=14) and a means to break barriers (f=15), reflecting their consciousness of engineering as a male-dominated field and their determination to prove stereotypes wrong (f=16) while serving as role models (f=13).

Proving stereotypes wrong emerged as a powerful motivation, transforming gender-based skepticism into determination. Participant 6 declared: "*When people express surprise that I'm studying engineering or make comments about it being a 'man's field,' it just makes me more determined to succeed. I'm not doing engineering despite being a woman—I'm doing it partly because I'm a woman who refuses to accept limitations based on gender. Every time I excel in a module or complete a difficult project, I'm proving that those stereotypes about women's capabilities are completely wrong*."

Aspiring to be role models (f=13) reflected awareness of representation gaps and desire to inspire future generations. Participant 10 explained: "*Growing up, I never saw women engineers—I didn't even know it was possible until much later. Now that I'm in engineering, I feel a responsibility to be visible, to show young girls that they can pursue this path too. Being a role model isn't just about my own success—it's about opening doors for others, about being the representation I never had*."

Challenging gender norms (f= 14) represented a conscious rejection of traditional expectations. Participant 17 articulated: "*My extended family expected me to study teaching or nursing—'appropriate' careers for women. Choosing engineering was an act of defiance against those gendered expectations. I'm demonstrating that women don't have to limit themselves to traditionally feminine careers. By challenging these norms, I'm creating space for other women to make unconventional choices without facing the same level of resistance*."

Breaking barriers (f = 15) captured participants' perceptions of themselves as pioneers dismantling structural obstacles. Participant 13 reflected: "*Every woman in engineering is breaking barriers, whether we intend to or not. We're entering spaces where we haven't been welcomed, challenging assumptions about who belongs in engineering, and slowly changing the culture of the field. I'm not just building a career for myself; I'm helping to create a more inclusive engineering profession that will be easier for the women who come after me*." These findings align with those of Pereira et al. (2023), who found that women in male-dominated STEM fields view their participation as both a personal achievement and a collective advancement for gender equity.

5.2 Theme 2 Challenges in Academic Experiences - Gender Bias and Resource Constraints

Participants' positive learning experiences were undermined by two interconnected academic challenges that disadvantaged their educational journey: gender-based disparities during practical sessions and insufficient institutional resources. When these barriers work in tandem, they create a network of obstacles that impact female students' success in engineering programmes.

5.2.1 Gender Bias in Practical Instruction

Gender bias in practical instruction emerged as the most pervasive challenge, manifesting through unequal attention in practicals (f=18), marginalisation during hands-on activities (f=17), lecturer bias (f=16), and passive participation by female students (f=14).

Unequal attention during practical sessions meant male students received more instruction, feedback, and encouragement. Participant 4 noted: "*Lecturers spend significantly more time with male students, explaining*

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concepts in greater detail. When I ask for help, I receive brief responses, as if investing time in teaching me isn't worthwhile. This differential treatment directly impacts my learning—I'm getting less instruction yet evaluated using the same standards." This created cumulative disadvantages in skill development and conceptual understanding.

Marginalisation during hands-on activities occurred through explicit exclusion and positioning that limited access to equipment. Participant 8 described: "*Male students position themselves in front of equipment, and when I try to participate, I'm told to 'just watch.' Lecturers rarely intervene to ensure equal access, so I often find myself on the periphery. Being relegated to observer status severely compromises my ability to develop practical competencies*." This reinforced gendered participation patterns, positioning women as less central to engineering practice.

Lecturer bias manifests through attitudes that communicate differential expectations. Participant 15 explained: "*Some lecturers refer to male students as 'engineers' while calling female students by first names, make jokes about women and technology, or express surprise when a female student demonstrates strong technical skills. One told me I did 'surprisingly well' on a practical exam. That bias communicates that our competence is an anomaly rather than an expectation*." These messages created environments where female students expended emotional energy managing dynamics rather than focusing on technical learning.

Passive participation (f=14) emerged as both a result of marginalisation and a self-protective strategy. Participant 19 reflected: "*Many female students have learned to stay quiet during practicals. When we assert ourselves, we're labeled 'difficult,' whereas male students showing the same assertiveness display initiative. We've adapted by becoming passive to avoid conflict, but this comes at tremendous cost to our learning and development as engineers*."

These patterns align with research showing that teachers' implicit biases reflect broader societal biases, with experimental studies demonstrating a bias against girls' abilities in STEM fields. Faculty members who attend "habit-breaking" workshops report greater awareness and take actions promoting gender equity (Carnes et al., 2023). Such unequal treatment fosters "stereotype threat," where awareness of negative stereotypes diminishes achievement and belonging (Steele & Aronson, 1995). Cheryan et al. (2017) emphasise that masculine cultures signal lower belonging for women, while exclusionary practices—including few role models and hostile cultures—erode social and ability belonging (Carlana, 2019).

5.2.2 Resource Limitations

Resource constraints created additional barriers, with outdated equipment (f=20) and inadequate learning tools (f=19) being nearly universal experiences, exacerbated by material costs (f=15) and resulting in practical skill gaps (f=13).

Outdated equipment meant learning on technology that no longer reflects industry standards. Participant 2 explained: "Much of our laboratory equipment is decades old. When we enter the workforce, we'll need to learn entirely new systems because our education hasn't kept pace with technological advancement. This makes us less competitive in the job market." This technological obsolescence undermined the preparation of work-ready graduates (Jesiek et al., 2023).

Inadequate learning tools encompassed insufficient software access, limited library resources, and material shortages. Participant 11 described: "We're told to share equipment because there isn't enough, meaning less hands-on practice. Software licenses are limited, so we can't work on our own computers. The library lacks current textbooks, and journal access is restricted. We're constantly working around resource constraints rather than having the tools needed to learn effectively." These limitations created obstacles that students at better-resourced institutions didn't face, producing "material constraints" that create epistemic injustice (Pawley & Tonso, 2023).

Material costs posed particular challenges for economically disadvantaged students. Participant 14 shared: "Some modules require us to purchase materials. For students from poor backgrounds, these costs create real hardships. I've chosen between buying materials and buying food, asked for extensions while saving money, and sometimes submitted inferior projects. These financial barriers limit our learning—we can't fully engage when constantly worrying about costs." This economic dimension disproportionately affected disadvantaged students, creating equity issues that perpetuate social inequalities (Slaton & Pawley, 2024; Cech & Blair-Loy, 2024).

Practical skill gaps represented the cumulative impact, demonstrating how material limitations translate into professional disadvantages. Participant 22 reflected: "I'm concerned my practical skills aren't at the level they should be. Because of limited equipment, large classes, and marginalisation as a woman, I haven't had sufficient hands-on experience. I can explain principles theoretically but am less confident about actually doing the work. That skill gap is worrying because employers expect graduates ready to work." This illustrates how resource constraints intersect with gender-based marginalisation to compound disadvantage (Foor & Walden, 2023).

5.2.3 Impact of Gender Bias on Learning

Beyond immediate exclusion, participants described cumulative psychological burdens. The need to prove competence (f = 17) emerged as a constant requirement, forcing female students to demonstrate abilities that were presumed in male students. Participant 14 articulated: "*Every time I walk into the workshop, I feel like I have* *to work twice as hard just to be seen as capable. Male students can make mistakes and move on—that's viewed as learning. But if I make one mistake, it confirms what people think about women in engineering. I can't just be a student learning; I have to be exceptional just to be considered adequate." This heightened scrutiny created "professional identity tax*"—additional emotional labour required to establish credibility (Dryburgh, 2023; McGee, 2024).

Ten participants described reframing bias as motivation, converting skepticism into determination. Participant 9 explained: "When people doubt my capabilities, I use that as fuel. I've turned their bias into motivation, which has helped me persist. However, I recognise this isn't healthy long-term—my motivation is partly reactive rather than purely my own goals. It's exhausting to constantly prove yourself." While effective for persistence, this strategy placed the onus on women to manage others' biases rather than addressing underlying discrimination (Riley & Claris, 2023).

The professional identity tax (f = 8) captured the burden of navigating bias while developing competencies. Participant 16 reflected: "There's a tax I pay that my male peers don't. I expend mental and emotional energy managing assumptions, proving my competence, and addressing messages that suggest I don't belong. That energy could be directed toward learning, but instead it's diverted into managing social dynamics. It's a tax on my cognitive resources, emotional well-being, and ultimately my learning outcomes." This taxation highlighted how discrimination created unequal educational experiences requiring additional labour from women (Lewis et al., 2023).

Stereotype threat (f=12) manifested as performance anxiety from awareness of negative stereotypes. Participant 21 described: "Sometimes during exams, I become aware that I'm evaluated against stereotypes about women's technical abilities. That awareness creates anxiety that interferes with performance—I become self-conscious and second-guess answers. The stereotype itself creates conditions for underperformance due to a psychological burden, rather than capability differences. It's an additional cognitive load I'm carrying." This phenomenon represented how societal bias infiltrated individual learning experiences (Spencer et al., 2023).

5.2.4 Balancing Responsibilities

Female engineering students described balancing academic demands with household duties (f=14) falling disproportionately on them due to gendered expectations, creating "time poverty" (f=11). Participant 8 shared: "*At home, I'm expected to cook and clean despite assignments due. My brothers don't have these expectations—they focus entirely on studies while I juggle coursework with household responsibilities. I study late after chores, then I'm tired in class. This creates a real disadvantage because I have less time to dedicate to studies, yet we're evaluated using the same standards*."

Academic workload stress (f = 18) was exacerbated by competing demands. Participant 12 explained: "*When you layer household responsibilities on top of academic demands, it becomes overwhelming. I'm constantly stressed about being a good daughter, sister, and student. Chronic stress affects my health, well-being, and academic performance. Male classmates deal with academic stress, but not this additional layer of family demands falling on daughters*." This compound stress reflected the intersection of gender expectations and academic pressures (Greenhaus & Allen, 2023).

Time poverty (f = 11) limited participation in supplementary learning activities. Participant 18 reflected: "*I can't participate in engineering societies or workshops that would enhance skills and professional networks. These enrichment opportunities are available but only accessible to students with time privileges. My time poverty means a more constrained educational experience, likely translating into fewer opportunities and less competitive credentials in the job market*." This created "hidden curriculum inequality"—differential access to unstated success requirements (Mullen, 2024).

Competing devotions (f=9) captured divided loyalty, creating internal conflict. Participant 20 articulated: "*I feel torn between devotion to family and becoming an engineer. Both require significant investment, and both suffer when I prioritise the other. It's an ongoing negotiation creating constant emotional strain. I wonder if male students experience this same conflict, or if they're allowed to be fully devoted to academic pursuits without expectation to fulfil family caretaking roles*." This emotional burden represented an additional challenge requiring ongoing negotiation between identities and responsibilities, reflecting the "double burden" women face in pursuing demanding professional education while maintaining traditional gender roles (Hochschild & Machung, 2023; Cech & Blair-Loy, 2024).

6. Conclusion

This study reveals that female engineering students at a South African university possess strong intrinsic motivation—driven by passion for engineering, problem-solving abilities, and desire to challenge gender stereotypes—alongside aspirations for economic empowerment and financial independence. However, their educational experiences are significantly undermined by three intersecting challenges:

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Gender bias in practical instruction manifests through unequal attention from instructors, marginalisation during hands-on activities, and resulting passive participation. This creates cumulative disadvantages in skill development, forcing women into peripheral roles. The psychological toll includes constantly proving competence, experiencing "professional identity tax," and managing stereotype threat—burdens that male peers do not carry.

Severe resource constraints—including outdated equipment, inadequate learning tools, and prohibitive material costs—affect all students but compound existing gender-based disadvantages, particularly as women already marginalised in practical sessions have fewer opportunities to compensate through additional practice.

Gendered domestic expectations create disproportionate household duties and "time poverty," resulting in a "double burden" that limits women's engagement with demanding engineering curricula in ways male students rarely experience.

These cumulative disadvantages demonstrate that recruiting women into engineering is insufficient without addressing the exclusionary cultures and inadequate resources that systematically undermine their learning. Achieving equity requires comprehensive interventions spanning pedagogical practices, institutional culture, resource allocation, and broader societal transformation.

7. Recommendations

The following recommendations are proposed to address the interconnected challenges facing female students in TVET engineering programmes:

7.1 Institutional Policy and Cultural Change

Institutions should audit their learning environments to identify and address gender-based barriers. This includes establishing explicit policies and procedures for addressing discriminatory behaviour and creating safe reporting mechanisms for students who experience bias or exclusion.

7.2 Infrastructure and Resource Development

Institutions should prioritise upgrading workshop equipment and ensuring adequate access to practical materials for all students.

7.3 Support Systems and Community Building

Formal mentorship programmes should be established that connect female students with successful women engineers and industry professionals. These programmes should provide academic support and career guidance, helping students navigate the challenges of engineering education while building professional networks. Additionally, peer support networks and communities of practice could be established to enable female students to connect, share experiences, and offer mutual support. These networks should be integrated into the formal curriculum and supported by institutional resources.

Institutions should actively promote the visibility of successful women in engineering through guest lectures, industry partnerships, and alumni engagement programmes. Exposure to positive role models can help combat negative stereotypes and inspire female students to persist in their academic pursuits.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Machaka & Singh-Pillay;* ***data collection:*** *Machaka;* ***analysis and interpretation of results:*** *Machaka & Singh-Pillay;* ***draft manuscript preparation:*** *Machaka & Singh-Pillay. All authors reviewed the results and approved the final version of the manuscript.*

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