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The Pedagogy of Troubleshooting in Electronics Engineering: Perceptions of Lecturers and Laboratory Technicians at a South African University

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Abstract

Troubleshooting a system or device is a fundamental requirement for an engineering career. Engineering faculty members, including lecturers and laboratory technicians, are responsible for equipping undergraduates with troubleshooting skills. However, faculty members in Science, Technology Engineering and Mathematics (STEM) education possess varying competency levels across their disciplines. In engineering education, the focus is particularly on engineering design. This study examined the perceptions of Electronics Engineering faculty members involved in teaching and training undergraduates, particularly regarding troubleshooting, one of the STEM-based core competency skills required in the electronics engineering industry. This research adopted an exploratory qualitative case study design conducted at a South African engineering university. Six faculty members were purposively selected and interviewed, four with previous industry experience and two without. The findings revealed that although faculty members recognized troubleshooting as a crucial STEM-based skill, particularly in engineering, they did not explicitly teach it as they did other competency skills. This study argues that engineering graduates may lack the necessary competencies for industry practice if troubleshooting skills are not integrated through appropriate explicit pedagogical strategies, such as inquiry-based learning, problem-based learning, and hands-on experiential methods supported by technology-enhanced learning tools. Aligning troubleshooting teaching with STEM pedagogies and leveraging educational technology, such as simulation-based learning, intelligent tutoring systems, virtual and remote laboratories, and AI-driven simulations, can enhance students' ability to diagnose and resolve engineering problems effectively.

Keywords: *Pedagogy, troubleshooting, engineering education, electronics engineering, perception*

INTRODUCTION

The significance of electronics troubleshooting in modern engineering education cannot be overstated (Jonassen et al., 2006). Troubleshooting is integral to Science, Technology, Engineering and Mathematics (STEM) disciplines, particularly in engineering, physics, and electronics, where students engage in laboratory courses involving circuit building and design. The ability to troubleshoot is essential, as students regularly build and test circuits, refine designs, and finalize engineering projects. Effective troubleshooting fosters technical competence and enhances problem-solving and critical thinking skills, aligning with core STEM education objectives. While previous research has examined students' troubleshooting practices and compared various learning models (Hochholdinger & Schaper, 2013; Van De Bogart et al., 2015; Dounas-Frazer et al., 2016; Van De Bogart, 2017), there is a notable gap in understanding faculty members' perceptions of teaching troubleshooting as a fundamental competency in engineering programmes. Although some studies have explored faculty perspectives in

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physics and electronics disciplines (Dounas-Frazer & Lewandowski, 2017), engineering as a discipline has received comparatively less research attention. Several models and techniques for teaching electronics troubleshooting have been proposed in engineering education (Hadgraft & Kolmos, 2020; Attia et al., 2018; Dounas-Frazer et al., 2016; Jonassen & Hung, 2006), yet these models predominantly emphasize conventional student-centered approaches without fully integrating technology-enhanced learning and evidence-based STEM pedagogies. Recent studies have highlighted the importance of integrating troubleshooting into STEM education frameworks. For instance, the S-T-E-M Quartet teaching framework emphasizes problem-solving as the overarching process, focusing on complex, persistent, and extended real-world problems at its core, thereby aligning with the need to incorporate troubleshooting skills in STEM curricula (Tan et al., 2019). Lui et al.'s (2024) research on collaborative troubleshooting in STEM contexts, such as high school students working on electronic textiles, further underpins the need for teaching approaches that address the multifaceted nature of troubleshooting across different domains.

Research Objectives

This study focuses on faculty members' perspectives on troubleshooting pedagogy in engineering. Faculty members, including lecturers with professional experience and laboratory technicians who directly engage students, play a crucial role in implementing institutional curricula and adhering to higher education policies. By exploring the teaching and learning of troubleshooting within a South African university of engineering, this study aims to highlight how seemingly omitted pedagogical approaches in engineering education, such as problem-based learning, inquiry-based teaching, and technology-enhanced learning (e.g., virtual labs, simulation-based training, and intelligent tutoring systems) can improve the integration of troubleshooting skills in engineering education.

The present study provides information about the perception of Electronics Engineering faculty members regarding the pedagogical approach to troubleshooting in the electronics engineering programme. Specifically, the research questions addressed in this study are:

1. What pedagogical beliefs do Electronics Engineering lecturers hold about troubleshooting skills?
2. How do these beliefs about the pedagogy of engineering relate to the teaching and learning of troubleshooting?
3. What is the rationale for adopting the pedagogical approach in teaching troubleshooting in the Electronics Engineering programme?

LITERATURE REVIEW

The role of lecturers and laboratory technicians in interpreting and implementing curriculum in engineering programmes

In university engineering education, faculty members play a pivotal role in implementing higher education curricula, particularly within STEM fields. According to Borrego et al. (2017), faculty members are responsible for designing, developing, and delivering courses that not only meet institutional requirements but also address the evolving needs of students in science, technology, engineering, and mathematics disciplines. This encompasses the integration of innovative teaching methods and up-to-date technological advancements to enhance learning outcomes. Beyond curriculum development, faculty members assess student learning and provide constructive feedback to support academic and professional growth. Their involvement in research and scholarly activities further informs and enriches their teaching practices, ensuring that course content remains relevant and reflective of current industry standards. This dual commitment to teaching and research fosters an environment where students can engage with cutting-edge developments in their respective fields. Moreover, faculty members often assume diverse roles such as mentors, collaborators, and community builders, which are crucial for student engagement and persistence in STEM disciplines. Hanauer et al. (2024), in their study on the professional identity of STEM faculty as lecturers of courses based on research experience, highlight their roles involve guiding students through complex problem-solving processes, facilitating collaborative projects, and creating inclusive learning communities that encourage exploration and innovation. By fulfilling these multifaceted responsibilities, faculty members significantly shape the academic experience and contribute to the success of their students in STEM education.

Faculty members in engineering in this study, comprising lecturers and laboratory technicians serve as role models and mentors for the next generation of engineers, helping to shape the future of the profession through their teaching, research and service. They help by integrating aspects of the curriculum that align with real-world work scenarios, such as internships, industry projects, entrepreneurship, and innovation hubs (Hadgraft & Kolmos, 2020). They are saddled with the duty of applying educational models that perfectly strike a balance between real-world experience and a structured academic environment. In the ever-changing landscape of higher education, faculty members hold a critical responsibility toward curriculum innovation in the 21st century. To ensure students in STEM disciplines, particularly in engineering education are equipped with the skills and knowledge necessary to succeed in the real world, lecturers must collaborate with laboratory technicians to stay up to date with the latest developments in their fields and integrate them into the curriculum. This includes facilitating internships, industry projects, entrepreneurship, and innovation hubs, which are essential for preparing students for practical challenges in their careers. It further embraces new technologies, utilizes cutting-edge research findings, and implements innovative teaching methods.

In the context of engineering education, laboratory technicians often work in laboratories and other hands-on environments. They are responsible for setting up and maintaining equipment, assisting with experiments, and troubleshooting technical issues. They also help lecturers develop and implement teaching materials that align with the curriculum's goals and objectives. In engineering and related courses, laboratory technicians are primarily responsible for helping students learn practically since they connect and involve them more than the lecturers do (Dounas-Frazer & Lewandowski, 2017). Furthermore, lecturers and laboratory technicians may collaborate with industry partners to provide students with real-world experiences and opportunities to apply their troubleshooting skills in practical settings. To ensure the curriculum is effective and relevant, lecturers and laboratory technicians interact across departments and solicit feedback from students and industry partners. Lecturers and laboratory technicians also make necessary adjustments to improve student performance to guarantee that the curriculum achieves its intended goals and objectives.

In 21st-century engineering education, lecturers and laboratory technicians are being forced outside their comfort zone, including changing what happens in the lecture room to better meet the industries', parents', and students' expectations and alter their perspectives on how the institution of higher education functions (Hadgraft & Kolmos, 2020). Lecturers and laboratory technicians can now serve as an important bridge between the institution and industry.

Enhancing the pedagogy of troubleshooting in engineering for future Industry workplace

In the field of engineering, well-developed troubleshooting skills are an absolute necessity and can make a significant impact on the success of any project (Diong et al., 2021). Engineers must be able to quickly identify and solve complex problems that arise during the design, construction or operation of various systems. Without these skills, the performance and efficiency of projects can suffer, and the safety and reliability of the final product may be compromised. Therefore, engineers must possess strong troubleshooting skills to ensure successful outcomes. There is a need to address the issue of engineering graduates' limited troubleshooting skills, as they may have gained little practical experience and underutilized test equipment during their undergraduate studies. Rivera-Reyes and Boyles (2013) observed that engineering graduates lack adequate troubleshooting skills due to a lack of hands-on experience and the underuse of test equipment. Providing more opportunities for hands-on training and emphasizing the importance of practical skills can help bridge this gap and produce better-prepared professionals in the industry.

Integrating technology-enhanced learning into engineering education pedagogy can significantly enhance troubleshooting skills development. Virtual labs, augmented reality (AR), and artificial intelligence-driven simulation tools allow students to engage in realistic problem-solving scenarios without the constraints of physical resources. For instance, remote labs enable students to interact with real-world engineering systems from any location, providing hands-on troubleshooting experiences (Aebersold et al., 2022). Similarly, AI-driven tutoring systems can offer personalized feedback to help students develop critical thinking and troubleshooting strategies (Zhang et al., 2023). AI-powered intelligent tutoring systems can analyze students' problem-solving approaches and provide real-time, personalized feedback to improve their troubleshooting strategies (Wang et al., 2022). Digital twins, which create real-time virtual replicas of engineering systems, enable students to interact with real-world scenarios remotely, helping them develop critical troubleshooting competencies even without physical lab access (Mourtzis et al., 2022).

It would be highly beneficial for lecturers and laboratory technicians to integrate these digital tools into their pedagogical approaches to prioritize the development of troubleshooting skills. This would not only foster the success of their students in engineering courses but also equip future engineering graduates with a valuable set of skills aligned with Industry 4.0 and smart manufacturing trends. Troubleshooting always emerges in the daily routine of engineering laboratory works and projects. According to Felder et al. (2000), engineering students must possess problem-solving skills, particularly in troubleshooting, at the undergraduate level. To ensure that engineering education provides training that matches industry needs in troubleshooting, lecturers and laboratory technicians must apply pedagogies beyond traditional teaching methods and embrace an integrative approach incorporating digital tools and intelligent learning systems. This could include game-based learning for fault diagnosis, IoT-enabled remote monitoring of engineering systems, and immersive AR troubleshooting environments, which can bridge the gap between theoretical knowledge and practical application (Nguyen et al., 2023). By leveraging these emerging digital learning environments, engineering educators can ensure that students develop troubleshooting skills in a dynamic, engaging, and industry-relevant method.

METHODOLOGY

Research Desain

This study focuses on the place of lecturers and laboratory technicians in the pedagogy of troubleshooting in Electronics Engineering education. The theory of space, as propounded by Lefebvre, which operates on three basic domains, namely, the conceived space, the perceived space, and the lived space, was adopted (Lefebvre & Nicholson-Smith, 2012). The outcome from each of the domains is compared with each other to locate where there is a high sense of practice. In other studies, the conceived space has been compared with the lived space of students' experiences (Fatokun, 2018; Middleton, 2017). In this study, the perceived space of lecturers and laboratory technicians is the domain to be interrogated for a place in the pedagogy of troubleshooting in engineering education. The theory provides the path to argue and locate the place of lecturers and laboratory technicians in the teaching and learning of troubleshooting for the Electronics Engineering education programme, both in interpreting and enacting the curriculum.

The study is an exploratory qualitative case study that took place at a university in South Africa that offers engineering programs. The study involved Faculty members in the Faculty of Engineering and comprised lecturers and laboratory technicians from the Department of Electrical and Electronics Engineering who constituted the population for the study. The methodology was guided by a phenomenographic approach to data collection and analysis. Phenomenography focuses on describing the participants' experience and the meaning given to the experience in a variety of ways, which is the focus of this study (Marton, 1988; Marton & Booth, 2013; Larsson & Holmstrom, 2007). Following the phenomenographic approach, the interview questions were categorized into three: the "What", the "How", and the "Why", which also guided the research questions of the study. The lecturers and laboratory technicians perceived troubleshooting in electronics engineering in diverse ways based on their experiences and these were reflected in their responses.

Participants

Purposive sampling was used to select the participants (Cohen et al, 2011). As argued by Cohen et al. (2011), like other case study research types of non-probability sampling techniques, purposive sampling seeks only to represent itself in a similar population rather than attempting to represent the whole, undifferentiated population. The lecturers and laboratory technicians were intentionally selected among the engineering faculty members of the university because they can best give relevant information to the researcher about the phenomenon of the study (Creswell & Creswell 2017). These faculty members are experts in engineering education pedagogy (Hadgraft & Kolmos, 2020), represents academic and industry perspectives (National Academy of Engineering, 2021), and possess diversity roles in engineering education which align with STEM education frameworks (Dounas-Frazer & Lewandowski, 2017; Borrego et al., 2020; Freeman et al., 2021). Qualitative studies prioritize rich, detailed data to explore complex issues deeply (Gregar, 2023). In qualitative studies, smaller samples, and in some case studies, a single sample is used to facilitate a comprehensive analysis of each participant's perspectives, leading to nuanced insights. Qualitative research aims to understand specific phenomena in-depth, making smaller samples appropriate (Creswell & Creswell 2017). Eight electronics and computer engineering lecturers and four laboratory technicians were available at the time of data collection. These participants have had experiences, at least in engineering education pedagogy and partly in industry and professional bodies. Out of these participants contacted for consent to participate, six electronics and computer engineering experts consented to participate in the study. Among the six participants, four had previous industry experience, while two were without industry experience. Following qualitative research ethics, the participants were identified by pseudonyms as *Olu, Gabriel, Tayo, Albert, King*, and *Lanre*. Four were lecturers, *Olu, Gabriel, Tayo,* and *Albert,* while two were laboratory technicians, *King* and *Lanre*. *Olu, Gabriel, Albert,* and *King* had industry experience, while *Tayo* and *Lanre* lacked industry experience.

Interview design

The qualitative interview was primarily used for data collection. Experts from the technology and engineering education staff validated the interview protocol for open-ended interviews. The participants choose the time, settings, and place for the interview. In-depth interviews were conducted with the participants to allow them to fully conceptualize their views and perceptions about the teaching and learning of troubleshooting in their years of experience in the university education system. Based on the case study methodology, as guided by Creswell and Creswell (2017), detailed interview data was collected from the participants who narrated their perceptions of troubleshooting the engineering education system.

Analysis

The lecturers and laboratory technicians perceived troubleshooting in electronics engineering in diverse ways based on their experiences, and these were reflected in their responses. The interview responses were subjected to careful transcription, interpretation, and analysis (Marton & Booth, 2013). The transcribed raw data was subjected to an iterative and comparative process; it involved continual sorting and re-sorting of the data (Åkerlind, 2012). This led to the categories of data description that had similar and non-similar characteristics from the respondents. The categories of description were thereafter put together to elicit the outcome space, which is the study's main finding. Subsequently, Levebvre's theory of space (Lefebvre & Nicholson-Smith, 2012), which helped to locate the place of troubleshooting in the teaching and learning space by the selected faculty members in Engineering Education, was used to wrap up the analysis.

Study limitations

It should be noted that this study is an exploratory qualitative case study research type (Creswell & Creswell, 2017) which considers a small sample size of six participants, all from the same institution in the electrical electronics engineering programme. It, therefore, indicates that there are likely other universities worldwide that are working in similar contexts or may decide to work in this context, expanding the scope and sharing similar profiles that could be useful to establish a generalization of findings or gain additional insights in their own situation. The findings of the current study, which we present shortly, are the in-depth understanding and perception of the participants involved and peculiar to the location of the present study.

FINDINGS AND DISCUSSION

The study finally arrived at three outcome spaces, which are presented as the main themes of the findings, namely, i) accommodation of troubleshooting in the pedagogical space of engineering education, ii) the practice of troubleshooting by the lecturers and laboratory technicians in professional training, iii) the rationale for the tradition of lecturers and laboratory technicians in troubleshooting.

Accommodation of troubleshooting in the pedagogical space of engineering education

In the first outcome space, four categories of description were identified in various ways and presented as responses by the participants. Their categories are put together as i) the teaching approach, ii) the mode of curriculum delivery, iii) troubleshooting as part of design, and iv) troubleshooting is embedded in solving complex engineering problems.

The approach of teaching delivery

Regarding the teaching approach delivery in the Electronics Engineering programme, the lecturers' responses show that their teaching approaches differ; it is a kind of approach that teaches students how to think before undertaking any task and not how to troubleshoot directly. However, they admitted that teaching troubleshooting was part of their training but not explicitly. The following excerpts explain their perceptions:

"Our approach is very different and always has been in this discipline, Electrical, Electronics and Computer Engineering discipline; the approach is to teach the students how to think and not to teach them solutions, it is very essential to understand this point. It (the approach) is different from standard teaching methodology" (Olu).

"The philosophy behind the approach differs, a person who studies at the university of technology (technichon) will design more with specification than an engineer in training from a conventional engineering university, the latter would take longer, he was not taught that approach" (Gabriel).

Mode of curriculum delivery

Participants identified the uniqueness of the curriculum and the time devoted to various projects and practical tasks as a necessary part of the curriculum for Electronics Engineering students to learn and develop troubleshooting skills. The following excerpts confirm this assertion:

"Students are given six months to deliver their final project work apart from the individual and group projects, first two to three months, they will bring some survey, some theoretical elaborate to see that everything is fine. But after the third or fourth month, they will start to design the hardware and that hardware, they are facing some problems in their connections, cabling, power supply there are so many other components like resistor, transistor, capacitor and other components" (Gabriel).

"The approach is different from standard teaching methodology, the difference between the technical university and the conventional engineers, in a technical university, they will teach you the solution, but we don't teach them the solution, we teach them how to figure it out" (Albert).

… "specifically, that for example when they are doing practical, often engineers have practical right from first year to their fourth year" (Tayo).

Participants' involvement in long-term different phases of laboratory work such as theoretical research, surveys, and practical hardware design suggests an experiential learning approach where students gradually transition from conceptual understanding to implementation. The description of the pedagogical distinction between technical universities and conventional engineering institutions reflected in the responses indicates an inquiry-based and self-directed learning approach, fostering critical thinking and analytical skills among students.

Troubleshooting as part of design

The lecturers and laboratory technicians in this category highlighted the design paradigm as an ideal environment for learning how to troubleshoot. The participants foregrounded design as the focus of problem-solving in engineering, whereby students solve troubleshooting problems inherently and implicitly. Troubleshooting is said to be embedded in design. While troubleshooting may not be explicitly written in the curriculum, it is embedded in the design process and practice. The following excerpts support the category of description:

"It is mostly design; I don't think there is any section called troubleshooting" (King).

"Technologist is more of hands-on, while engineers are more of design; in engineering, students are not tested on troubleshooting. They are judged on the outcome of their design" (Albert).

> *"So, the troubleshooting comes up as they engage in their work" (Gabriel).*

The responses suggest that engineering education focuses more on design theory and implementation than teaching diagnostic and repair skills systematically. This raises questions about whether troubleshooting should be formally integrated into engineering programs to better prepare students for real-world challenges where problem identification and resolution are crucial.

Troubleshooting is embedded in solving complex engineering problems

The participants' perceptions slightly differed from those in the first group as they emphasised that they did not teach troubleshooting in the Electronics Engineering programme but identified teaching as one of their major focuses to solve complex engineering problems. Solving complex engineering problems was perceived as one of the pivots of real professional practice in an electronics engineering career. Their narratives are presented as follows:

> *... "specifically, that for example, when they are doing practical, often engineers have practicals right from first year to fourth year" (Tayo).*

> *... "eehm, what they are all given is task to do, task as practical. When they are given the task, they are supposed to work in a certain way" (Albert).*

> *"So, we make sure students know how to use breadboards, and how to transfer the circuit to printed boards, how to bring the components together. You have to give specific attention to instrumentations, because the instruments have to be set correctly first in order to test the circuit and calibrations to be sure it is correct" (King).*

These responses reflect a hands-on problem-solving approach where students must design circuits and test, troubleshoot, and refine their work through correct instrumentation and calibration. These insights suggest that engineering education aims to develop students into competent problem-solvers by combining theoretical knowledge with hands-on application and precision in technical execution.

The teaching practice of lecturers and laboratory technicians on troubleshooting skills

Practical laboratory and design tasks

The participants reported that they usually assign students design tasks on previously defined problems. With such tasks during the regular practical laboratory, students get involved in troubleshooting skill practices, however, they are not explicitly taught how to troubleshoot.

> *"Troubleshooting task is specifically by giving the students two practical in their laboratories in their third year. In the second year, we have four experiments and troubleshooting is involved because they design their own circuit on the breadboard; These are previously defined problems or tasks run by second-year students every year" (Gabriel).*

> *"Although we don't identify any section as problem-solving, we are teaching them problem-solving by default" (Olu).*

… "eehm, what they are all given is task to do, task as practical. When they are given the task, they are supposed to work in a certain way" (Albert).

"I think basically (lecturers and laboratory technicians) read the notes and explain a little about troubleshooting" (King).

Lecturers and laboratory technicians believed that troubleshooting was being taught by self-engagement with practical laboratory and design tasks.

Written examination

In describing how Electronics Engineering lecturers engaged students on how to troubleshoot, one participant spoke on assigning about 50% of the students' written examination to troubleshoot. This is a theory-based approach to learning troubleshooting.

"For troubleshooting, what happens in their question paper, it is in their examination, we are giving them more than 50% of their questions related to this type of troubleshooting. That is a new structure, which they don't know and we give the circuit in their examination" (Gabriel).

This approach describes the place of science in a theory-based engineering programme.

Competency test in engineering

The lecturers and laboratory technicians in this category shared similar views that no engineering student would be taught or tested on competency in troubleshooting in engineering programme, rather, what was being tested is competency in engineering design, and in problem-solving.

"There is no specific training for troubleshooting. There is no specific training as such. You can't get coached. Even apprenticeship, you would have people coming in out there and they would show you on a board what to look for to solve. But university level, you don't have that type of training" (Lanre).

"That is easy, it definitely, the process of problem solving and defending engineering design and taking a design and making it physically fit to function; If that process has been tested a couple of times into the degree, automatically, troubleshooting it's been fulfilled and tested" (Tayo).

"What is required is the theory of how things work. Fault finding comes in when things doesn't work how it should work. And it's the techniques which come up all the time to find why those things are not working and that comes with time" (Albert).

The responses indicate that competency in troubleshooting is not directly taught but emerges as a byproduct of problem-solving, theoretical understanding, and repeated engineering practice.

Organic troubleshooting

In the case of organic troubleshooting, participants reported that students are given a little reinforcement in their practical lessons and lab work, but mainly, they learn the art through their self-efforts. It is worth noting that organic troubleshooting in design was highlighted as also embedded in electronic engineering programmes. Organic troubleshooting is regarded as a natural, inherent, and intrinsic style of learning how to troubleshoot, whereby students learn to deconstruct the process and practice troubleshooting independently. The participant presented it this way in the excerpt below:

"It (the circuits) wouldn't work; they have to troubleshoot what's wrong. Definitely comes troubleshooting skills, but it's more organically touched" (Tayo).
"So that they pick it (the self-acquired troubleshooting skills) up; it's more organically touched right from their first year to fourth year" (Albert).
"Troubleshooting is a requirement that they pick up in their training" (Lanre).

Organic troubleshooting is foregrounded in place of a structured troubleshooting process. Since there was no provision for a formal troubleshooting learning process, students worked their way through learning to troubleshoot; they naturally picked up the skill on their own. The emphasis of participants in this description category indicates that most times, the Electronics Engineering programme does not deliberately focus on troubleshooting as a skill; students do learn how to troubleshoot on their own organically.

The rationale for the tradition of lecturers and laboratory technicians in troubleshooting

The objective of the Electronics Engineering programme

The participant regarded the objective of Electronics Engineering as creativity. Creativity is seen as the ability to do things in a novel way. Creating and designing new ideas and solutions to complex engineering problems is the focus of the engineering profession. It is opined that the ability to create must result from multiple skills the engineering students have developed during their training. The objective is not just to prepare the students for a specific industry but to prepare them to fit into any electronics engineering industry. It is a broad aim.

"The objective (in engineering field) is creativity, creativity is core" (Olu).
"You need to have a an enquiring mind,… If you don't have an enquiring mind, then you have problems" (Albert).
"Students are not tested on their ability to troubleshoot per se. They are judged on the outcome of the specifications they are given" (King).

The scope of engineering work

According to participants' narratives, engineers work with high-level, complex engineering tasks, while technologists work at a low level. Technologists are assumed to be trained to perform better at the circuit construction level, which hones their troubleshooting skills.

"Because what happens with the engineers is that they have so many devices, so many works, so they are not necessarily perfect" (Gabriel).

"Normally engineering job stops at design; normally, that is where engineering jobs stops and then handed over to the technician to put together" (Albert).

"We are not there to watch them troubleshooting. See end result (of design) and give them certification" (King).

> *"I wouldn't be surprised if technicians are taught troubleshooting more than engineers; engineers end up designing stuff, and simulation stuff which require troubleshooting in a simulation environment" (Tayo).*

These responses suggest that the scope of engineering work is heavily design-oriented, with troubleshooting often being left to technicians or conducted in simulated environments rather than physical systems. However, industry expectations demand troubleshooting skills, indicating a gap between academic preparation and real-world engineering roles. This implies that engineering education may need to integrate practical troubleshooting skills better to align with industry requirements.

Compliance with changes emanating from professional organisation

The recent pressure from ECSA requires engineering programmes to introduce some professional courses so engineers can often end up in managerial positions. This will require engineering programmes to drop engineering courses such as quantum mechanics to be replaced with courses on professional practice and economics.

> *"In fact, there was pressure from ECSA. ECSA requires us to introduce professional courses, so engineers often end up in managerial positions, so we are going to introduce courses on professional practice and economics. So, we are going to drop quantum mechanics for professional courses" (Lanre).*

> *… "they arrive in the workforce in a new job as someone who has acquired some broad skills, with a good foundation in natural science and from a conventional university, a good foundation in design" (Tayo).*

The findings showed that the curriculum is design-based and theory-based. The lecturers and laboratory technicians are guided by changes in the discipline curriculum as the policymakers and accreditation agents give directives. The lecturers' and laboratory technicians' perceptions indicated that troubleshooting was not taught formally in Electronics Engineering. Students learned through regular, informal troubleshooting techniques even though they were not explicitly taught, nor was the apprentice model used for them.

Discussion

The findings from the study raised three critical issues: What are the perceptions of lecturers and laboratory technicians on the pedagogy of troubleshooting in engineering education? How was the practice of teaching troubleshooting conducted in core engineering education? Why did pedagogy differ from other disciplines that require troubleshooting in their curricula?

The findings underscore the centrality of troubleshooting as a core competency for engineering graduates, aligning with the required learning outcomes in STEM disciplines. Faculty members acknowledged that troubleshooting is a crucial skill for engineers to thrive in their careers. Yet, their pedagogical approaches varied, reflecting differences in teaching methodologies across STEM fields such as Science, Mathematics, and Technology. This reflects the study's contribution to STEM pedagogy and teaching innovation by highlighting the perspectives of lecturers and laboratory technicians on troubleshooting education in engineering. Rather than explicitly teaching troubleshooting as a structured skill, lecturers and laboratory technicians preferred an implicit, experiential approach, allowing students to develop troubleshooting abilities through hands-on projects, the engineering design process, and problem-based learning.

While this aligns with constructivist learning theories, which emphasize learning through experience, it contrasts with the more structured cognitive and technical hands-on approaches advocated by Dounas-Frazer et al. (2016). This divergence in pedagogical perspectives suggests that while engineering education fosters problem-solving skills through experiential learning, a lack of explicit teaching may create gaps in students' ability to troubleshoot effectively in real-world scenarios. This study also reinforces the findings of Diong et al. (2021), who argued that strong troubleshooting skills can significantly impact an engineer's ability to succeed in the industry. However, for engineers to be industry-ready, technologically adept, and confident in their problem-solving abilities, educational strategies must be deliberate and structured rather than incidental. Research has shown that faculty beliefs about teaching directly influence teaching practices, which in turn shape student learning outcomes and attitudes toward knowledge acquisition (Borrego et al., 2013; Colbeck et al., 2002; Gow & Kember, 1993; Trigwell & Prosser, 1996). If faculty members rely solely on students "figuring out troubleshooting on their own", several pedagogical challenges may arise. Some students may acquire the skill only to meet academic requirements rather than to develop a deep, transferable understanding. In contrast, others may struggle due to a lack of guidance, resources, or structured learning pathways. This study calls for teaching innovation in STEM education, advocating for a balanced integration of explicit troubleshooting teaching, hands-on practice, and digital learning tools to ensure that engineering graduates acquire robust, industry-aligned troubleshooting competencies that prepare them for the evolving demands of the workforce.

Second, the lecturers and laboratory technicians highlighted the prevalent approaches adopted to teach troubleshooting in engineering education. Lecturers and laboratory technicians identified several pedagogical strategies, including design tasks, cognitive written examinations, competency-based assessments, and organic troubleshooting through hands-on experience. However, they largely expected students to acquire troubleshooting skills passively as they prepared for their viva and engaged in project-based learning. This contributes to STEM pedagogy and teaching innovation by indicating the prevalent approaches used to teach troubleshooting in engineering education and highlighting the gaps in current teaching methods. Despite the importance of troubleshooting as a core engineering competency, existing engineering curricula often prioritize general problem-solving, systematic design, analytical reasoning, and critical thinking skills over explicit troubleshooting teaching (Passow, 2012; Trevelyan, 2007; Mickelson et al., 2001). Additionally, Male et al. (2010) observed that while engineering design is highly regarded, troubleshooting remains underemphasized in formal teaching. The research underscores the need for structured troubleshooting pedagogy, where explicit teaching models integrate both cognitive and technical problem-solving approaches (Jonassen & Hung, 2006; Ross & Orr, 2009; Tufur et al., 2012). Technology-enhanced learning environments should be incorporated to enhance the 21st-century STEM education frameworks to strengthen troubleshooting proficiency. Emerging teaching innovations such as virtual simulations, augmented reality (AR), artificial intelligence-based tutoring systems, and problem-based learning (PBL) platforms have been shown to enhance students' ability to diagnose and resolve engineering problems in real-time (Finkelstein & Winer, 2020; Kolodner et al., 2024; Fuhrmann et al., 2022). By integrating these technology-driven approaches, STEM educators can bridge the gap between theoretical knowledge and hands-on troubleshooting expertise, ultimately better-preparing graduates for industry demands.

Third, the study's findings indicate that lecturers and laboratory technicians serve as critical mediators between Electronics Engineering students and regulatory bodies, such as the Council on Higher Education (CHE) and the Engineering Council of South Africa (ECSA). Their role extends beyond classroom teaching to shaping curricular alignment with national engineering standards, thus influencing how troubleshooting is integrated into STEM education. Applying Lefebvre's theory of space, lecturers and laboratory technicians represent the "perceived space" in engineering education, where practical competencies such as engineering design, complex problem-solving, scientific investigations, technical communication, and professional management take precedence over troubleshooting skills (CHE, 2015). This reflects broader trends in STEM education, where policy-driven shifts dictate how skills are prioritized (Middleton, 2017). Lefebvre and Nicholson-Smith (2012) argue that over time, knowledge systems have been restructured by hierarchical forces, leading to changes in pedagogical approaches that emphasize structured problem-solving and abstract thought over hands-on troubleshooting skills. Despite the increasing reliance on automation and expert systems, Pease (2013) asserts that human intelligence in troubleshooting remains indispensable, as artificial intelligence (AI) and automated diagnostic tools cannot fully replicate the cognitive flexibility required to address unpredictable technical failures.

Recent studies corroborate this, emphasizing the need for AI-assisted learning environments that enhance, rather than replace, students' troubleshooting abilities (Bumbacher et al., 2022; Finkelstein et al., 2020). Integrating digital learning environments, intelligent tutoring systems, and remote laboratories into engineering education offers an innovative approach to developing students' diagnostic and problem-solving skills (Mason & Shah, 2021). To ensure that STEM education remains aligned with industry needs, troubleshooting pedagogy should not be sidelined but incorporated into modern teaching strategies. This can be achieved through technology-enhanced experiential learning, simulation-based assessments, and AI-driven adaptive learning models, bridging the gap between academic knowledge and real-world engineering practice (Bates et al., 2023).

Troubleshooting is a critical competency in STEM education, particularly in engineering disciplines, where students must diagnose and resolve complex technical issues. Numerous studies highlight the importance of troubleshooting skills in science, technology, engineering, and mathematics fields, emphasizing their role in problem-solving, design iteration, and real-world engineering applications (Dounas-Frazer et al., 2016; Dounas-Frazer & Lewandowski, 2017; Fatokun, 2018). Despite this, research indicates that many undergraduate engineering students struggle with troubleshooting, limiting their ability to fulfill original design specifications in practical projects (Diong et al., 2021). The pedagogical challenge in STEM education is that troubleshooting is often underemphasized compared to structured problem-solving and theoretical knowledge. Traditional engineering curricula prioritize systematic design, critical thinking, and mathematical analysis often if troubleshooting emerges naturally through project-based learning (Male et al., 2010). However, studies suggest that explicit teaching in troubleshooting, combining cognitive strategies with hands-on technical training, produces more competent graduates (Jonassen & Hung, 2006; Ross & Orr, 2009; Tufur et al., 2012). To enhance STEM pedagogy, educators should integrate digital tools, artificial intelligence (AI), and immersive learning environments into engineering curricula (Bumbacher et al., 2022; Mason & Shah, 2021). Intelligent tutoring systems, virtual and remote laboratories, and AI-driven simulations can enhance students' ability to diagnose and resolve technical faults in engineering design projects (Finkelstein et al., 2020). Furthermore, adaptive learning models and real-time analytics can provide personalized feedback, fostering deeper engagement and self-regulated learning in troubleshooting education (Bates et al., 2023). Addressing the troubleshooting skills gap in undergraduate engineering programs requires a systematic teaching approach that blends cognitive, hands-on, and technology-enhanced learning strategies. This pedagogical shift aligns with industry demands for graduates who can analyze, diagnose, and resolve engineering failures, ensuring they are better prepared for the workforce.

CONCLUSIONS

In this case study, findings from the perception of lecturers and laboratory technicians revealed that, the integration of soft skills into engineering programs by regulatory bodies such as the Engineering Council of South Africa (ECSA) and the Council on Higher Education (CHE) has significantly influenced the structure of engineering curricula. While including professional competencies such as communication, teamwork, and leadership are valuable, it has, in some cases, diminished the emphasis on fundamental engineering competencies, such as troubleshooting skills. This shift highlights the need for a pedagogical re-evaluation to ensure that engineering graduates are equipped with general problem-solving abilities and specialized technical skills required for industry applications. Troubleshooting is a critical yet often underemphasized skill in undergraduate electronics engineering education. Despite its importance in diagnosing and resolving design and operational failures, it remains an implicit rather than explicit component of many curricula. Engineering educators, including lecturers and laboratory technicians, play a pivotal role in ensuring that troubleshooting skills are systematically integrated into structured learning experiences rather than being acquired informally through project-based activities. To enhance engineering education, undergraduate electronics engineering programs must embed structured pedagogy on troubleshooting, incorporating cognitive and hands-on learning approaches. By doing so, students can specialize in technical troubleshooting techniques, equipping them to engage effectively with industry practices and handle the complexity and uncertainty of real-world engineering challenges. Moreover, the inevitable design failures and technical setbacks encountered in engineering practice necessitate formal training in troubleshooting methodologies, ensuring that graduates are prepared to solve complex problems systematically. By adopting a structured approach to troubleshooting education, electronics engineering programs can bridge the gap between academic learning and industry expectations, fostering graduates who are both technically proficient and adaptable to the evolving demands of engineering practice.

To enhance STEM education and teaching innovation, Electronics Engineering lecturers and laboratory technicians must have strategies to assess and measure students' troubleshooting abilities as a core professional competency. The lack of explicit recognition of troubleshooting as a measurable learning outcome has resulted in its omission from formal assessment frameworks within Electronics Engineering programs. To bridge this gap, troubleshooting should be integrated into program objectives, with structured assessment methods that evaluate cognitive and hands-on problem-solving skills. Further research is essential to determine the extent of faculty involvement in undergraduate teaching on troubleshooting techniques. Future studies should expand beyond traditional electronics contexts to explore troubleshooting applications in emerging fields such as robotics, artificial intelligence (AI), and machine learning, investigating how students develop creative problem-solving strategies when working with modern electronic systems. Additionally, research should foster industry-university collaboration, engaging advisory boards to assess the level and depth of troubleshooting skills that engineering graduates must attain to meet evolving industry demands. By advancing structured troubleshooting pedagogy and assessment, Electronics Engineering programs can better align STEM education with industry expectations, ensuring graduates are technically proficient, adaptable, and prepared for real-world engineering challenges.

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