UNIVERSITY OF KWAZULU-NATAL

INYUVESI YAKWAZULU-NATALI

COLLEGE OF HUMANITIES

School of Education

EXPLORING THE PLACE OF TROUBLESHOOTING IN AN UNDERGRADUATE ELECTRONICS ENGINEERING EDUCATION PROGRAMME AT A UNIVERSITY IN SOUTH AFRICA

JONATHAN OLANREWAJU FATOKUN

216073768

DECEMBER

2018

EXPLORING THE PLACE OF TROUBLESHOOTING IN AN UNDERGRADUATE ELECTRONICS ENGINEERING EDUCATION PROGRAMME AT A UNIVERSITY IN SOUTH AFRICA

by

JONATHAN OLANREWAJU FATOKUN
216073768

Thesis submitted in fulfilment of the academic requirements for the degree of Doctor of Philosophy of Education in the Cluster of Science and Technology Education
School of Education
University of KwaZulu-Natal

Supervisor:
PROF. B. P. ALANT

DECEMBER 2018

ABSTRACT

Whereas the ability to identify, formulate and solve engineering problems is considered an essential learning outcome for an engineering education curriculum, there seems to be ambivalence around the place of troubleshooting in electronics engineering programmes. Yet, the practice of troubleshooting is deemed a requisite generic engineering competency skill in industry. The San Diego 24-hour blackout in 2011 is a commonly cited case to highlight the importance of electronics troubleshooting in modern electronics engineering. In this regard, engineering troubleshooting is seen to play a vital role in the safety and economic wellbeing of a nation. However, many universities offering engineering education programmes have tended to omit or put little emphasis on troubleshooting in their curriculum, thereby creating a lacuna between theoretical knowledge and problem solving skills in real-world troubleshooting. This current study, therefore, sought to explore the place of troubleshooting in an undergraduate electronics engineering education programme at a South African university. This study argues that, without the appropriate instructional pedagogy in troubleshooting, a tension between "theory" and "practice" in engineering education will continue to exist.

A qualitative case study research design was employed to interrogate the following three broad questions: (i) Is troubleshooting accommodated within an electronics engineering programme? (ii) How is the electronics engineering programme enacted? (iii) What informs how the programme was enacted? Phenomenography and Lefebvre's theory of space were used as analytical and theoretical frameworks, respectively. Phenomenography allowed for the delineation of the different ways in which troubleshooting was conceptualised by the various participants. Lefebvre's theory of space allowed for the differentiation of the three domains that characterise the place of troubleshooting within the undergraduate electronics engineering programme, namely, the conceived space (government policy), the perceived space (institutional curriculum and instruction) and the lived space (fourth year engineering students). With respect to the first question, the findings revealed that this question was domain dependent. With respect to the first domain, the findings indicate that troubleshooting was not afforded any place at all (0% affordance), whereas the second domain showed a mixed response from the participants (lecturers and technicians). A 50% versus 50% affordance was recorded for this domain. In contrast, the third domain's findings indicated 100% affordance. With respect to the second question, the findings were that the electronics engineering programme was broadly enacted through individual-based, theory-based and design-based practices, indicating a total absence of explicit troubleshooting teaching practices. Further, findings from the third question reveal that there was no explicit teaching of troubleshooting in the electronics engineering education programme.

While the practice of troubleshooting is deemed a requisite generic engineering competency skill, the non-explicit teaching of troubleshooting as a core part of electronics engineering curriculum has implications for policy, practice and research. Whereas the CHE and ECSA policy documents that guide engineering education in South African universities make no provisions for the place of troubleshooting in electronics engineering education programme, the findings suggests that such omission or silence in the policy impacts the learning outcome of electronics engineering students, who graduate without the requisite expertise needed to solve real-life troubleshooting problems. This requisite expertise, as the literature affirms, should unequivocally form an important element of the electronics engineering curriculum practice and discourse in South African universities. The implications of the findings in this study further suggest the need to critically look at the possible gaps between theory and practice, and the dynamics of institutional influences on practices. Further research is suggested with a view to narrow the gap between theory and enactment in the electronics engineering education curriculum.

DECLARATION

I, **Jonathan Olanrewaju Fatokun** declare that:

i) The research reported in this thesis, except where otherwise indicated is my original work;

ii) This thesis has not been submitted for any degree or examination at any other university;

iii) This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

iv) This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

   a. Their words have been re-written, but the general information attributed to them has been acknowledged;

   b. Where exact words have been used, their writing has been placed within quotation marks, and referenced.

v) The work described in this thesis was carried out in the School of Science and Technology Education, University of KwaZulu-Natal, from 2016-2018 under the supervision of Dr Busisiwe Precious Alant (Supervisor); and

vi) The Ethical Clearance No. HSS/1559/016D was granted prior to undertaking the fieldwork.

Signed: ____________________________ Date: ____________________________

As the candidate's Supervisor, I, Prof Busisiwe Precious Alant, agree to the submission of this thesis.

Signed: ____________________________ Date: ____________________________

ETHICAL CLEARANCE

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

07 October 2016

Mr Jonathan O Fatokun 216073768
School of Education
Edgewood Campus

Dear Mr Fatokun

Protocol reference number: HSS/1559/016D
Project title: Exploring the Place of Troubleshooting in undergraduate Electronics Engineering Education Program at a University in KwaZulu-Natal.

Expedited Approval

In response to your application dated 21 September 2016, the Humanities **&** Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol have been granted **FULL APPROVAL.**

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number. Please note: Research data should be securely stored in the discipline/department for a period of 5 years.

The ethical clearance certificate is only valid for a period of 3 years from the date of issue. Thereafter Recertification must be applied for on an annual basis.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

....

Dr Shamila Naidoo (Deputy Chair)

/px

cc Supervisor: Dr AP Alant
cc Academic Leader Research: Dr SB Khoza
cc School Administrator: Mrs B Bhengu-Mnguni, Mbalenhle Ngcobo, Philisiwe Ncayiyana, Tyzer Khumalo

Humanities & Social Sciences Research Ethics Committee
Dr Shenuka Singh (Chair)
Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Telephone: +27 (0) 31 260 3587/8350/4557 **Facsimile:** +27 (0) 31 260 4609 **Email:** ximbap@ukzn.ac.za / snymanm@ukzn.ac.za / mohunp@ukzn.ac.za
Website: www.ukzn.ac.za

DEDICATION

This thesis is dedicated to God, the only wise God.

ACKNOWLEDGEMENTS

First and foremost, my sincere gratitude goes to God the author and finisher of my life's journey. Without Him, the actualisation of this dream wouldn't have been possible. Faithful is He who has promised and fulfilled His promises.

I want to register my profound appreciation to my able supervisor, **Prof Busisiwe P. Alant** for her seasoned scholarly support in this research. She introduced me to qualitative research for the first time in my research journey and she did it well – and to another terrain, that of phenomenographic research methodology. She is a teacher-supervisor. Once again, many thanks for your patience and in-depth mentoring.

I would like to thank those who have helped make this work possible, and to apologize in advance if I have left anyone out.

I owe an immeasurable gratitude to my wife, **Bimbola Charity Fatokun** for her support, understanding, patience, perseverance and motherly care to my family during the period of pursuing this programme. She deserves a great honour, we earned the degree together.
And to my lovely children, **Isaiah, Virtuous and John**, for being patient and enduring with daddy's long absence. Your future will be brighter than daddy's own in Jesus name.

I appreciate all the participants who participated in the research. Without their cooperation, this study would not have been possible. Special thanks to the Dean and head of School of Engineering (UKZN), **Professor Cristina Trois**, the acting dean, **Professor Jules-Raymond Tapamo**, the lecturers, laboratory technicians and students of Electrical, Electronics and Computer engineering programme who participated in the study.

I cannot but express my gratitude to the Vice Chancellor, Ekiti State University, **Professor S. O. Bandele** for approving my study leave and TETFUND for funding the programme. My appreciation goes to all the former and present HODs, Curriculum Studies department and now Vocational and Technical Education department, past and present Deans, Faculty of Education (a great family), of Ekiti State University. Many thanks to Dr (Pastor) J.O. Oke, God be with him and lift him higher in his career.

I as well appreciate all the staff of the department of Vocational and Technical Education, Professor O. V. Adeoluwa, Professor R. O. Famiwole, Professor A. A.Owojori, Professor G. B. Olowoyeye, Dr P. O. Ogundola, Dr A. O. Olaoye. Dr Olaniyi, Dr J. O. Ogunmilade and my colleague, Mr. J. O. Adameji.

I also appreciate members of staff of the Science and Technology Education Cluster, Edgewood campus, University of KwaZulu-Natal who have contributed one way or the other to the success of this research. Thanks to Dr Asheena Singh-Pillay, Pastor Bakare, Dr. Legg-Jag Dagogo Williams, Fasinu George, Victor Nnadozie and to others not mentioned because of space.

I cannot but find a place for my brethren in the faith, pastors and members of Deeper Life Campus Fellowship, KwaZulu-Natal province for their fellowship and prayers. First and foremost, to my late Pastor Adewumi Aderemi and his family, Dr. Olusanya Micheal and family, Dr. Peter Merisi and family, bro Adeniyi, and the rest of them. I owe you a lot of appreciation in this space, you are all very important to me, and I say to all, God bless and reward you. Edgewood brethren you are so great, remain blessed, Maranatha.

LIST OF ABBREVIATIONS

ABET	Accreditation Board for Engineering and Technology
CATE	College of Advanced Technical Education
CHE	Council on Higher Education
EA	Engineering Australia
ECSA	Engineering Council of South Africa
ENAEE	European Network for Engineering and Technology
FET	Further Education and Training
IEA	International Engineering Alliance
NATED	National Accredited Technical Education Diploma
NCV	National Certificate (Vocational)
ND	National Diploma
NSE	Nigeria Society of Engineers
SETA	Sector Education Training Authority
TVET	Technical Vocational Education and Training

TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

CHAPTER 1

CONTEXTUAL BACKGROUND TO THE STUDY

1.0 Introduction

This study sought to explore the place of troubleshooting in undergraduate electronics engineering programme at a university in South Africa. It makes a case for the inclusion of troubleshooting within the undergraduate electronics engineering programmes. It argues that without a focus and appropriate instructional pedagogy in troubleshooting, a tension between “theory” and “practice” in engineering education will continue to exist. Whereas the ability to identify, formulate and solve engineering problems is considered an essential learning outcome for any engineering education curriculum, there seems to be some ambivalence around the place of troubleshooting in electronics engineering programmes. Yet, within these programmes, the practice of troubleshooting is deemed a requisite generic engineering competency skill.

The place of electronics troubleshooting in modern electronics cannot be overemphasized (Jonassen, Strobel & Lee, 2006). According to Jonassen et al., it has the potential for promoting national work force development and global competition with other countries in electronics technology. Van Hentenryck and Coffrin (2015) further argue that engineering troubleshooting plays a vital role even in the economic and human welfare of a nation. For instance, they report that, during the San Diego 24-Hour blackout in 2011, an estimated loss of around 100 million US dollars was recorded, leaving aside the major sections of the population without lighting, refrigeration, communication, air conditioning and other social amenities (ibid). It is in this regard that various authors argue for the need for an adequately skilled work force in engineering troubleshooting skills to handle emerging problems in electronics technology (Pate & Young, 2014; Pate & Miller, 2011; Jonassen, Strobel & Lee, 2006). Clough (2004) argues that if countries are to maintain their “economic leadership and sustain” their share of highly-technological jobs, they must prepare the engineers of tomorrow for future technological and societal changes and to acquire new knowledge quickly and apply it to emerging problems” (emphasis mine). As argued by Jonassen et al. (2006, p. 139), practising engineers are “hired, retained and rewarded for their ability to solve workplace problem (as well as social problems” as illustrated above). Therefore, there is a dire need for engineering students to learn this requisite generic engineering competency skill. This obviously has implications for engineering education curriculum.

The nature of the problematic is such that many conventional universities offering engineering education programme globally have tended to omit and or/ put less emphasis on troubleshooting in their curriculum, thereby creating a lacuna between theoretical knowledge and problem-solving skills in real-world troubleshooting.

In South Africa, engineering competencies for professional practice and measurable engineering learning outcomes are set out in the white paper documents from the Council on Higher Education [CHE](2015) and Engineering Council of South Africa [ECSA](2017). The Council on Higher Education (CHE) is an independent statutory body situated in South Africa for the quality control of higher education and is responsible for the stipulation of qualification standards for the Bachelor of Engineering and Bachelor of Science in Engineering in South Africa (BEng/BSc (Eng)). On the other hand, the Engineering Council of South Africa (ECSA) provides the standards and procedures system for accreditation of programmes for meeting the educational requirements for all engineering professional categories in South Africa. Eleven measurable learning outcomes and competency skills were stipulated in the two policy documents, out of which problem solving is first mentioned (CHE, 2015; ECSA, 2017). In both documents (CHE and ECSA), “problem solving is defined as the ability to identify, formulate, analyse and solve complex engineering problems creatively and innovatively” (CHE, 2015, p. 9; ECSA, 2017, p. 5).

Furthermore, engineering programmes are presently found at various levels in the curriculum. Table 1 below shows that electronics engineering is offered at five levels of education:

- Secondary school (Grades 10-12);
- Further education and training college (NCV2-NCV4);
- National Technical Diploma (N1-N6);
- University of technology (ND 1& 2 and B. Tech);
- Conventional university (BEng and BSc (Eng)).

A critical analysis of the South African electrical/electronics engineering curriculum shows that troubleshooting or maintenance and repairs is stipulated as a learning outcome at four levels only: the secondary school, FET College, National Technical Diploma and University of Technology (but only at diploma level). It is significant to note that troubleshooting was not specified in the Bachelor of Technology, Bachelor of Engineering and Bachelor of Science in engineering curricula, as illustrated in Table 1 below.

Table 1: The place of Troubleshooting in Electrical/Electronics Curriculum

	School				FET Colleges				N4-N6 IDC Training Institute				DUT-Diploma		DUT-B.Tech		Conventional University			
	G10	G11	G12		NCV2	NCV3	NCV4		N4	N5	N6		ND-1	ND-2	1 Year		Y1	Y2	Y3	Y4
Electrical (Power Systems)	√	Nil	√	Electrical Infrastructure Construction	Nil	√	√	Electrical Eng	√	√	Nil	Electrical (Power and Plant Stream)	Nil	√	Nil	Electrical Eng.	Nil	Nil	Nil	Nil
Electronics	Nil	Nil	√					Electronic Eng	√	Nil	√	Electronic Comm Eng.	√	Nil	Nil	Electronic Eng.	Nil	Nil	Nil	Nil
Digital Electronics	Nil	Nil	Nil					Industrial Instr. Eng	Nil	Nil	Nil	Instrumentation and Control	Nil	Nil	Nil	Computer Eng.	Nil	Nil	Nil	Nil

Key: The tick (√) indicate where troubleshooting appears in the curriculum

Table 1 The place of troubleshooting in electrical/electronics curriculum

(Sources: CAPS, 2014; IDC, 2016; DUT Handbook, 2016 and CAES, 2016)

Based on the above, we can safely conclude that South African universities, like their counterparts globally, omit or do not put much emphasis on troubleshooting in their curriculum. Electronics courses, as argued by Dounas-Frazer and Lewandowski (2017), are ideal settings whereby electronics engineering students could practise and hone their troubleshooting skills because students naturally engage in troubleshooting during most of their practical designs and projects. Could the omission of troubleshooting at South African universities imply that their programmes do not adequately prepare their students for effective real-world troubleshooting expertise, as argued by Shin, Jonassen and McGee (2003)? Schraagen and Van Berlo (2000) are emphatic that, without the appropriate type of programme and instruction, there could emerge a significant gap between a students' troubleshooting knowledge and their ability to solve problems in real-life situations. In other words, partial or total oversight of attention to certain practices, troubleshooting in particular, in the curriculum could result in a tension between "what is being taught" and "what is required in real-world practices".

1.1 Tension between theory and practice in engineering education

According to Reynolds and Seely (1993), engineering education is believed to have begun in the 18th century with early industrial work based on practical skills and crafts, and latter led to the establishment of technical school. Early engineering education, as traced by Jorgensen, in

Crawley, Malmqvist, Ostlund and Brodeur (2007, pp. 220-222), was based on a vision of technical development and the use of systematic, analytic approaches such as those practised for engineering programme in early polytechnics, which was done to equip students with the capacity to address unknown future challenges. This vision permeated the European countries and the United States around the first half of the 19th century. For instance, in France, the first idea of engineering education developed and was promoted through the building of the first polytechnic in 1792, according to the structure of French government institutions and industry (Crawford, 1996). According to Crawford (1996), the polytechnic marked the first era of higher education in the history of engineering education. However, in the early 19th century, engineering education became inspired by industry needs in France such that, besides working in government institutions, engineers had close alliance with industries and were involved in creative engineering practices (ibid.). The inception of new engineering education later led to the establishment of other types of institutions of higher education in engineering, several of which focused on emerging sectors of industrial significance in mining, mechanical, agriculture and factories with new technology-based equipment. In Northern Europe, two models of engineering education were prominent in practice (Gispen, 2002). One model was based on practical education that recruits skilled craftsmen from industry and trades and was developed from technical schools around the late 19th century to upgrade the skilled workers coming from apprenticeship-based craft training (ibid.). This training provided more basic theoretical subjects for the workers coming from industry to advance their skills in engineering. The second model is a university-like academic engineering which is differentiated from the discipline-oriented university education in natural science. These were academically trained engineers coming directly from secondary schools. The purpose of having these two models was to produce two different classes of engineers, one practically skilled engineers, the other theoretically trained engineers.

In the United Kingdom, engineering grew from the practical, skilled crafts and was kept from the universities and the sciences. Engineering education only found its way into the higher education system as polytechnic institutions. Unlike other European countries where the government defined the qualifications of engineers through their educational programmes, the British system of accreditation emphasized practical skills and engineering experiences. In the United States, engineering education started with polytechnic institution like the UK system. The first established polytechnic was founded in 1824 and acquired its modern name in 1862 (Crawley et al., 2007). Engineering education in the US emphasized practical, industrial, and agricultural experiences for students, with comparatively less emphasis on mathematics and sciences. Although there were calls for other approaches, such as applying a scientific and theoretical approach to engineering problems in engineering education in the early 20th century, precisely during the 1920s and 1930s, American engineering education maintained largely the practical and industrial orientation to training until the advent of World War II (ibid.). This idea spread among the intellectuals in the US and Europe, which was believed to have influenced the change after the World War II period.

The greatest historical change in engineering education is believed to have happened after the Second World War (World War II) because it marked the beginning of transition from practice-based engineering to science-based engineering education programmes. Both the US and Europe embraced the theoretically oriented university and technical engineering education. This, according to Crawley et al. (2007), signified a transition from practice-based curriculum to an engineering-based model, commonly referred to as “engineering science revolution”. The engineering programme that emerged after the Second World War attempted to establish a science base for engineering which created a new elite of theoretical universities and technical schools of higher education in both the United States and Europe (Reynolds & Seely, 1993).

However, around the 1990s, some basic issues of concern began to emerge as to the changes that had happened to engineering education and the relevance of the development in engineering education since after the World War II (Crawley et al., 2007). Such concerns raised included the lack of practical skills in modern engineering training, the lack of relevance for industry of the science being taught, and the kind of analytical qualifications being awarded in engineering education compared with the earlier visions of engineers as being creative design engineers and innovators of future technologies. It appears that the introduction of science based engineering model which emphasized science and knowledge structure around technical disciplines created a gap in engineering education. Jorgensen (2007) claims that the broad innovative capacity and knowledge required to produce creative design engineers able to cope with modern technological change seem to be lacking in engineering education.

Concerns have also been raised on how engineering programmes in many parts of the world experienced the transition from a practice-based curriculum to an engineering-based model, commonly referred to as the “engineering science revolution” (Crawley et al., 2007). According to these authors, the earlier intention of this revolution was to have a change in the system so as to engage engineering students in a rigorous, scientific foundation that would equip them to address unknown future technical challenges in engineering. Unfortunately, unintended consequences were experienced, as this changed the culture of engineering education (ibid). One outcome was a decline in the practical skills and experience of engineering students. Academic qualifications in theory and research-based engineering practice took over the platform in place of engineering programmes and practices. Thus, there was a shift in the culture of engineering education leading to a diminished perceived value of key skills and attitudes, namely, the technical, knowledge skills and personal, interpersonal skills that has been the hallmark of engineering education (ibid). The net result was thus the development of tension between engineering theory and practice.

Another significant issue raised regarding the transition from a practice-based curriculum to a science-based engineering curriculum was that modern engineers are required to engage in all phases of the lifecycle of products, processes and systems that range from the simple to the extremely complex (Crawley et al., 2007). Though there is an inclusion of practical training in the curriculum of engineering education, the structure seems to maintain the hierarchy and roles of theoretical training in the programme (ibid.). The challenge is how change can be introduced to relieve this tension between theory and practice in engineering education, in order to respond to the needs of industry and society (the external stakeholders), to reform engineering education programme and educational approaches, and to transform the culture of engineering education.

There was another significant concern in engineering education for engineering students. Emphasis in their career is primarily oriented to the acquisition of high level basic science engineering principles combined with analytical capability, and not to the old tradition of practice-based skills. This shift is a current practice in 21st century engineering that draws on a solid foundation of science more than on old traditional engineering practices. (Crawley et al., 2007). However, Crawley et al. (2007) assert that this was not created to displace the excitement of engineering, which was based on creating the opportunity for students to design and build to enrich their experience. Unfortunately, the priorities of engineering education seem to have been misplaced by the engineering students, which signified that something was lost in the process and the gap requires being filled. The 21st century undergraduate engineering education requires a holistic view of engineering whereby students are able to combine the learning of theory and practice in modern engineering technology and meet the requisite demands of industry and society.

In the South African context, engineering education started as technical college institutions that only provided engineering theory for apprenticeships offered in a range of engineering educational programmes (Van der Bijl & Taylor, 2016). In the early 2000s, precisely around 2001, these technical colleges were restructured into Further Education and Training Colleges (FET) (ibid.). The FET colleges were later renamed Technical Vocational

Education and Training (TVET) colleges in order to align with the global trend to meet the emerging demands for skilled workforce (Petersen, Kruss, McGrath & Gastro, 2016). According to these authors, though TVET colleges have their own origins in the technical colleges of the 1920s in South Africa, one of the curricular goals in the 21st century is to integrate theory, practice and teaching to prepare students for workplace competencies. TVET provides education to two groups of students; those pursuing vocation-focused schooling rather than a traditional matric, and those who have completed their schooling and seek a tertiary qualification but who do not qualify for university entrance. Thus, TVET colleges offer two main qualification streams, namely, the National Accredited Technical Education Diploma (NATED) programmes, which form the theoretical component of the artisan training system for apprentices from industries, and the National Certificate (Vocational) designate as NCV programmes, which emphasizes practical and vocation-specific learning. As part of the country's construction of education and training sector authorities during the post-apartheid era, the Sector Education Training Authority (SETA) was formed around 1998 and was re-established in 2005 (DoL, 2005). The focus of this change was to modernize the old apprenticeship system to learnerships, thereby facilitating a bilateral relation, by the introduction of employer/student and education provider collaborative learnerships. A learnership is structured as a combination of unit standard-based learning and practical work experience that leads to a qualification on one of the levels of the National Qualification Framework (ibid.). The learnerships were intended to be delivered by TVET colleges in partnership with the SETAs and industry.

Higher education in South Africa has been influenced by the British model of engineering education since the colonial era (Kloot & Rouvras, 2017). According to these authors, the discovery of gold before the turn of the 20th century provided the motivation for the emergence of the first engineering schools in South Africa. The curriculum model was similar to that of an engineering science bachelor's degree, which was distinctly theoretical even though it contained some degree of practical engineering. Much later, in the late 1960s, in order to meet the shortage of skilled personnel in the country, another form of engineering training, designated as Colleges of Advanced Technical Education (CATEs), were established across the country (D'Almaine, Manhire & Atteh, 1997). The colleges were later converted to "technikons", which can be compared to the polytechnics of UK and US. The technikons qualify students with an engineering diploma after two years of theoretical study, followed by one year of experiential training at a co-operating, accredited industrial company. However, the privileging of theoretical over practical knowledge in South Africa has been resulting in a sharp difference in and tension between the statuses of these two types of institutions. While the graduates of universities of engineering were designated as professional engineers, the graduates from technikons were referred as engineering technicians. Recently around 2001, South African Department of Education restructured university education and renamed the technikons as universities of technology where Bachelor of Technology (BTech) qualifications are awarded (Kloot & Rouvras, 2017). Other conventional universities offering engineering programmes award the Bachelor of Engineering and Bachelor of Science in engineering (BEng & BSc (Eng)). The difference between the two categories of engineering universities is that one is regarded as practically oriented while the other theoretically oriented built after the pattern of 21st century science-based engineering curriculum. This observed difference could as well create a dichotomy between theory and practice in conventional engineering programmes in South Africa, which necessitates an empirical investigation.

1.2 Rationale and significance of the study

My experiences as an undergraduate and postgraduate student and lecturer highlighted the importance of troubleshooting as a key component in engineering education, particularly in electronics engineering. My experience shows that the troubleshooting skill competency is not explicitly taught or included in the curriculum or policy statements for electronics engineering education programmes despite the fact that it is a more problematic component to teach to electronics engineering students than the theory component. Over the years, I have noted that providing the requisite competencies in the learning of electronics courses and producing successful students requires a balance in both its technical and theoretical expertise. This became a motivation towards my endeavour and quest to further interrogate and explore the actual place of troubleshooting in electronics engineering programmes. By this means, I seek to significantly contribute to the body of electronics engineering education and improve the quality and nature of undergraduate electronics engineering education programmes.

In this regard, this study explores the place of troubleshooting in the electronics engineering programme at a university in South Africa. However, it does not directly look at the experience of learning electronics engineering but rather looks at the medium by which electronics engineering is learned through troubleshooting. This approach is similar to the one employed by Alant (2001) in her study of first year university students' experiences of introductory physics, as drawn from their approaches to problem solving. When solving engineering problems, students are not dealing with only one case or type of problem, but with a variety of problems. The problem-solving tasks in electronics engineering education programme are multi-faceted in that they would always link with several other problem types. In other words, engineering problems are solved through a combination of various experiences which are synthesized within the process. In the regular design tasks given to students, for example, students are explicitly required to come up with a working design at the completion of the task. This requirement would however constitute, within the larger goal of the task, its own point of focus and its own experience. To meet design objectives in engineering, parts are integrated together to form a whole (synthesising), and then steps are taken to dissect the whole into pieces (analysing). It would however be impossible to meet the design objectives without attending to all the elements of problem solving in an engineering task. Some of these elements include troubleshooting and are intertwined into the problem-solving experiences of engineering students, which are experienced in various ways. It is the variation in the ways of experiencing troubleshooting in electronics engineering that is the focus of this study. Hence, the variations in the participants' awareness of the place of troubleshooting, as a key generic competence in electronics learning, are explored in the study.

An understanding of the place of troubleshooting in electronics engineering based on all the participants' experience will significantly benefit engineering education policy, practice and research. With respect to policy, it stands to inform the electronics engineering policies that are guiding engineering education in South Africa and globally. The recognition by policy makers and developers in engineering education that troubleshooting is a key, hard-core, technical skill could make the electronics engineering profession more robust and fascinating for prospective students. With respect to practice, the recognition of troubleshooting as a medium of learning in modern technology affords and accords its place in the pedagogy of the programme as one of the key 21st Century skills. Finally, with respect to research, Lefebvre's theory of space has demonstrated that there should be a balance between the conceived (engineering educational policy), the perceived (institutional curriculum and instruction) and the lived (electronics engineering students). The theory unfolds the imbalance experienced in institutional practices vis-à-vis policy and curriculum which could provide a theoretical basis for further research in electronics engineering education and in engineering programmes in general and for guiding educational institution researchers.

1.3 Aim(s) of the study

As stated earlier, the study aimed to explore the accommodation and enactment of troubleshooting in undergraduate electronics engineering education programme in a university at KwaZulu-Natal in South Africa. This was done in order to understand the place of troubleshooting in undergraduate electronics engineering education programmes. To achieve this aim, the following specific objectives were set for the study:

1. To explore the place of troubleshooting within undergraduate electronics engineering programmes through the following sources:
   - Policy documents - CHE and ECSA documents;
   - The university electronics engineering handbook;
   - Lecturers - electronics engineering lecturers;
   - Technicians - electronics engineering laboratory technicians;
   - Students - fourth year electronics engineering students.
2. To understand how an electronics engineering programme should be or is enacted by the above five sources.
3. To find out what informs how an electronics engineering programme should or is enacted by the above five sources.

1.4 Research questions

In order to achieve the set objectives the following three broad research questions guided the study:

1. Is troubleshooting being accommodated in the electronics engineering program:
   - Policy documents - CHE and ECSA documents?
   - University electronics engineering handbook?
   - Lecturers - electronics engineering lecturers?
   - Technicians - electronics engineering laboratory technicians?
   - Students - fourth year electronics engineering students?

   a) If so, what is foregrounded in the electronics engineering programme?

   b) If not, what is foregrounded in the electronics engineering programme?
2. How should the electronics engineering programme be or is being enacted by:
   - Policy documents - CHE and ECSA documents?
   - University electronics engineering handbook?
   - Lecturers - electronics engineering lecturers?
   - Technicians - electronics engineering laboratory technicians?
   - Students - fourth year electronics engineering students?

3. What informs how the electronics engineering programme should be or is being enacted by:

- Policy documents - CHE and ECSA documents?
- University electronics engineering handbook?
- Lecturers - electronics engineering lecturers?
- Technicians - electronics engineering laboratory technicians?
- Students - fourth year electronics engineering students?

A qualitative case study research design was employed to interrogate the above three broad questions. An exploratory case study research was conducted through in-depth and detailed data collection instruments using two major sources of information, namely, documents and open-ended interviews. Following Creswell (2014), in this study, a single case of troubleshooting in the university electronics engineering education programme was studied. Figure 1 illustrates the structure of the inquiry method adapted for the study in five consecutive stages, indicating how the study was conducted from the data source to the final conclusion of the study. The first stage illustrates the main sources of data generated for the study, namely, documents and open-ended interview. The second stage describes how the interview data was generated from research participants. This was followed by the third stage, which describes how the two data types were processed and analysed to answer the three broad research questions. In order to answer the critical question of the study dealing with *what is the place of troubleshooting in a university electronics engineering education programme*, the fourth and five stages provide the guide to this end.

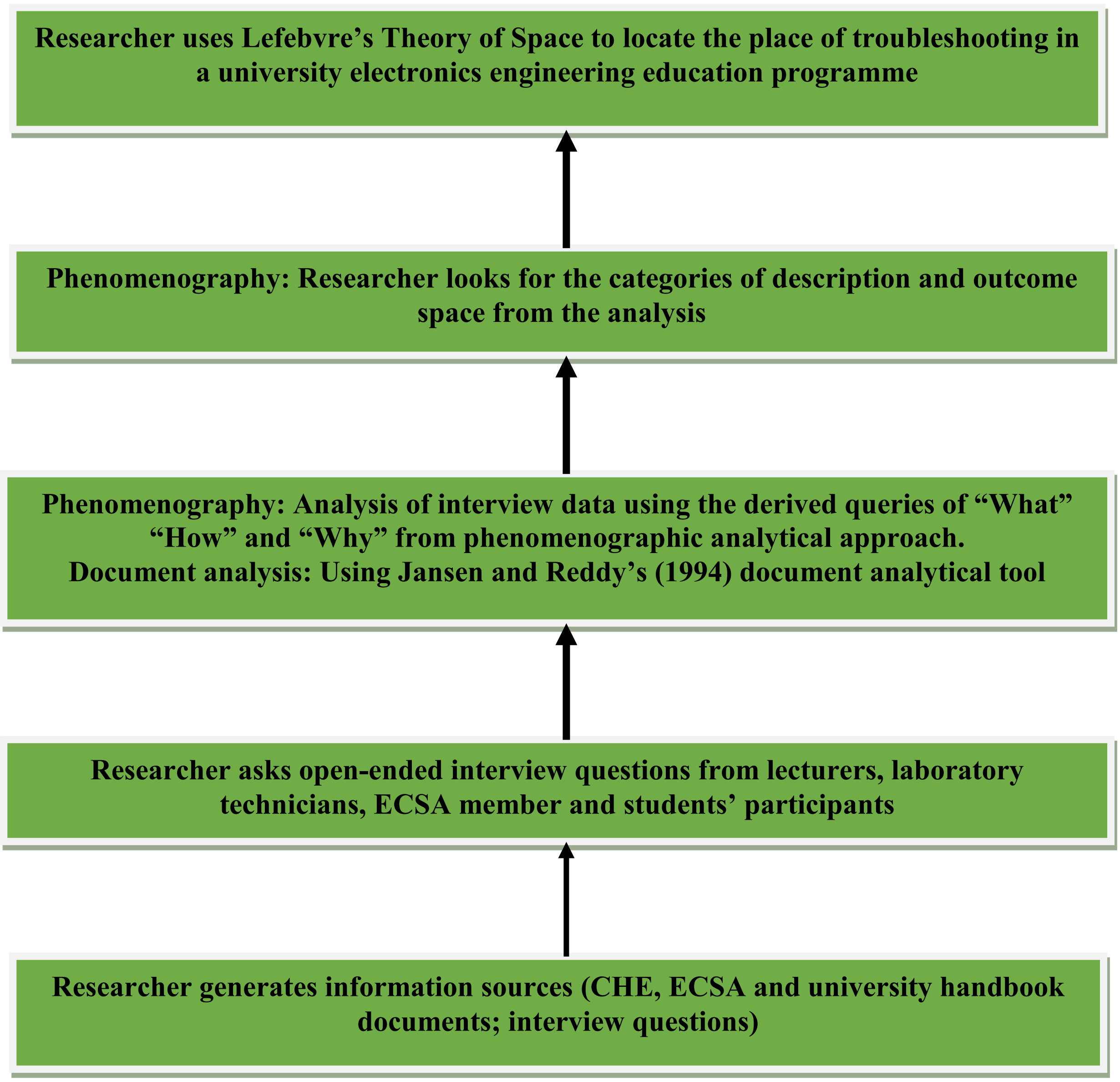


Figure 1 Structure of the inquiry method, adapted from Creswell (2014, p 100)

Phenomenography, as espoused by Ference Marton, and the theory of space, as advocated by Lefebvre, were used as analytical and theoretical frameworks, respectively. Phenomenography allowed for the delineation of:

(i) the different ways in which troubleshooting was conceptualised by the various participants;

(ii) the different ways in which troubleshooting was enacted in the electronics programme and

(iii) what informed the way in which the electronics programme was enacted.

The phenomenographic analytical method considers two aspects of analysis, namely, the referential and the structural aspects of the ways of experiencing a phenomenon, as shown in

Figure 2. According to Marton and Booth (2013), the referential aspect of a phenomenon under study highlights the direct object of the phenomenon, giving it a particular meaning according to the way it is experienced. This is the overall meaning attached to the phenomenon. It describes what influences the meaning attached to the phenomenon, in other words, what is the meaning attached to troubleshooting by various participants in this study, and what is their general perception about it in electronics engineering programmes? It answers research question one as described in Figure 2 below. The second aspect is the structural aspect which describes how people practise something (Marton, Tsui, Chik, Ko & Lo, 2004). The structural aspects describe how the participants and policy represents the structure of the place of troubleshooting in electronics engineering programmes. It is further referred to as the approach to a phenomenon, and is divided into two aspects, the internal and external horizon (Marton & Booth, 1997, p 88). The internal horizon in this study referred to how troubleshooting is being enacted in electronics engineering programme, that is the strategies employed in electronics engineering programmes. While the external structure describes what influences how electronics engineering programme is being enacted, the intention underlying the strategies employed in the programmes. The internal horizon answers research question two while the external horizon answers research question three.

Lefebvre's theory of space allowed for the differentiation of the three domains that characterise the place of troubleshooting within the undergraduate electronics engineering programmes. In accordance with Lefebvre's theory, these were categorized as:

(i) the conceived space (government policies – e.g. CHE, ECSA);

(ii) the perceived space (institutional curriculum and instruction) and

(iii) the lived space (fourth year engineering students).

The theory of space as propounded by Lefebvre (2012) operates on three basic analytical categories as described above to locate the place a phenomenon. It interrogates the three categories to determine whether there is a sense of relationship and connection between the three spaces. Lefebvre demonstrates that there ought to be a balance in the internal relationships between the three spaces in the production process otherwise, a lack of balance should be interrogated, and the imbalance should be corrected accordingly. Lefebvre's triad, as stated above, was employed to situate the place of troubleshooting in an electronics engineering programme by interrogating the findings from CHE and ECSA policy documents, the institutional curriculum and instructional pedagogy, and students' responses. Drawing on Lefebvre's theory in this study, it is argued that the conceived space of CHE and ECSA did not afford a space for troubleshooting in electronics engineering policy documents, the perceived space partly afforded a space informally while the lived space afforded a high sense of place for troubleshooting in electronics engineering programmes. These affordances showed a lack of theoretical unity among the three spaces. Lefebvre's theory is concerned with inequality in space and its implications, which makes it very relevant in the present study. The theory provides the path to argue and locate the place of troubleshooting in electronics engineering education programmes.

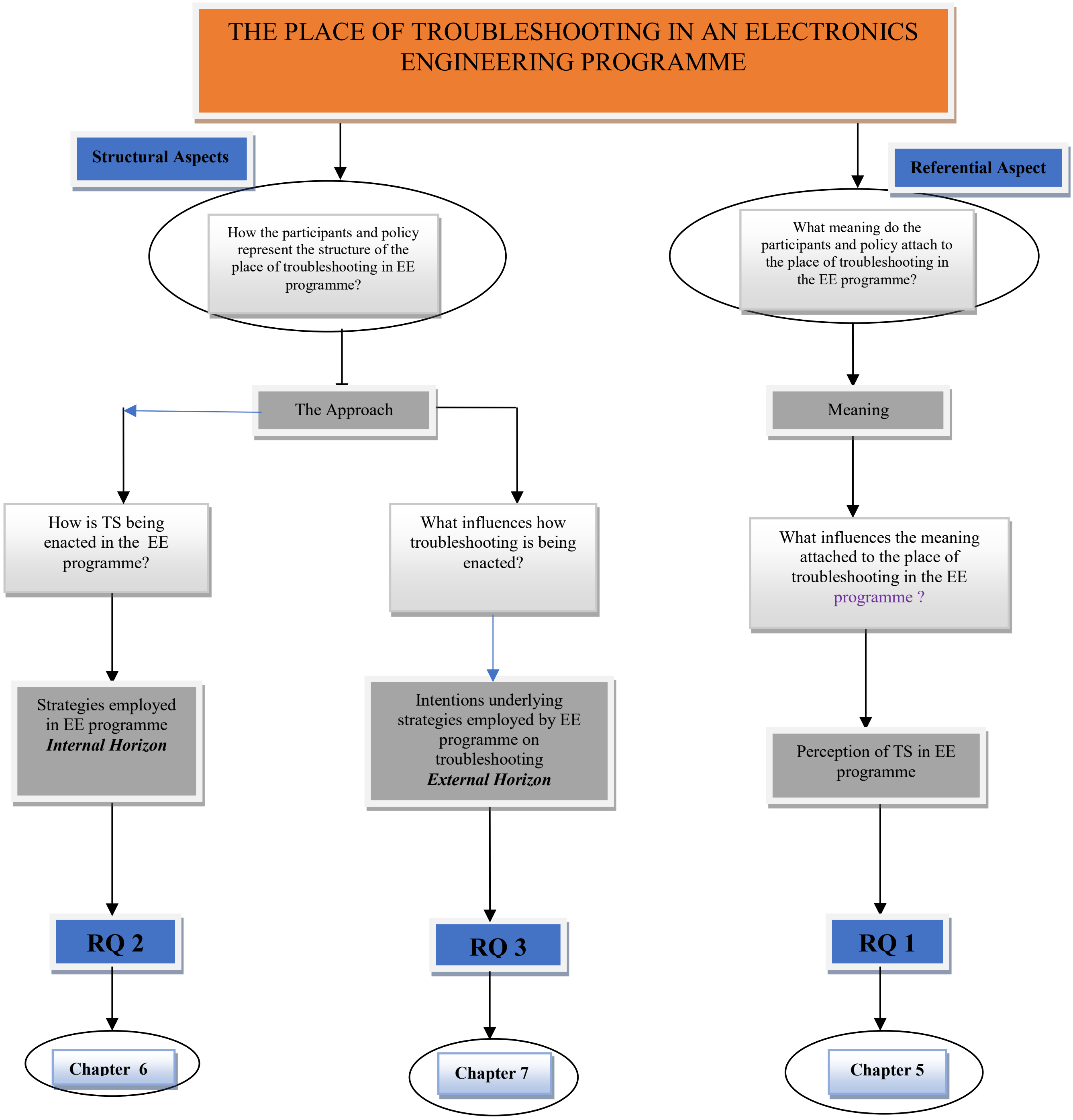


Figure 2 Schematic representation of the place of troubleshooting in an electronics engineering programme (adapted from Alant, 2001)

1.5 Overview of the study

This study comprises nine chapters.

Chapter 1 consists of the introduction, where I have presented the background to the study, the tension between theory and practice in engineering education, the rationale for the study, objectives and research questions that guided the study. Essential terms used are also defined operationally for the sake of clarity for readers.

Chapter 2 consists of the literature reviews underpinning the study, presented under six major subheadings. The literature was explored to reveal the gap the study intends to fill. The chapter gives a review of the context of troubleshooting, troubleshooting in electronics engineering, troubleshooting as a sub-set of problem-solving in engineering education, the place of troubleshooting in engineering workplace and the relevant approaches to the pedagogy of troubleshooting. The chapter further provided a brief review of some models already designed for troubleshooting to unfold its significance in pedagogy and related literature on troubleshooting in engineering education.

Chapter 3 presents two sections consecutively; firstly, the analytical and secondly theoretical framework adopted in the study. The study adopted *phenomenographic* analytical approach to analyse the interview data generated in the study by using the three queries of "what", "how" and "what informs the how" to interrogate the data. The concern was to interpret, analyse and answer the three broad research questions of the study. The theoretical framework of Lefebvre on *the production of space* was used to discuss the findings from the study. The study draws upon the triads of the conceived, the perceived and the lived space of Lefebvre's theory to locate the place of troubleshooting in undergraduate electronics engineering programmes. Lefebvre's theory illuminated the inequality experienced on the place of troubleshooting among the three spaces in university electronics engineering education programmes.

Chapter 4 provides the description of the methodology applied in the study. It comprises the research design, the paradigm and the methodology used in answering the research questions. It also presents the process of data collection, sampling procedures, ethical issues, method of data analysis and the research rigour. The chapter describes the method employed in the exploration of the three research questions. It describes the application of Jansen and Reddy's (1994) tool for document analysis and the phenomenographic analytical tool for interview data analysis.

Chapters 5 to 7 present the analysis of the data generated from the field. Chapter 5 presents the analysis of research question 1, as stated above, using the phenomenographic analytical process. This chapter was divided into six sub-sections in order to answers the questions, interpret their results and present findings. The variations in participants' experience of the meaning and perception of troubleshooting in an electronics engineering programme were explicated in categories of description in the six sections of the chapter. Chapter 6 presents the results of the analysis of research question 2 and its findings. The chapter describes the structure of how the participants discern the approach to troubleshooting in electronics engineering and the various way the approach was experienced in groups of categories of description. Chapter 7 provides the analysis and findings of research question 3 as well as the summary of findings for the three research questions. The findings to research question 3 were aligned to the external horizon, whereby the intention underlying the approach was described in categories of description. The categories of description were summed up into four outcome spaces in the summary of findings.

Chapter 8 consists of the discussions of findings for the study. The discussion was based on the application of Lefebvre's theory. Three main sub-headings were discussed to portray the three moments of Lefebvre's triads. Using the outcome spaces that emerged from the analysis in previous chapter, Lefebvre's theory is used to establish the place of troubleshooting among the three spaces of the government policy, institutional instruction and students.

Chapter 9 consists of the final conclusion of the study. The conclusion was drawn on the main phenomenon and subject of the study - the place of troubleshooting in undergraduate electronics engineering education programmes. It comprises the implications of the study for policy, practice and research. Suggestions for further studies were presented.

1.6 Operational definitions of terms used in the study

DESIGN: is a component of engineering process; to conceive, fashion in mind or invent an engineering product. It is a regular course or module included in the curriculum of electronics engineering programmes, accomplished through the process of application of scientific and mathematical principles to practical ends (Pahl, & Beitz, 2013, p. 1).

ENGINEERING DESIGN: it is the method that engineers use to identify and solve engineering problems. It embraces courses and modules offered in engineering education programme (Pahl, & Beitz, 2013, p. 1).

ENGINEERING DESIGN PROCESS: a series of steps that engineers follow to come up with a solution to a problem (Jones & Ertas, 1996).

TROUBLESHOOTING: the complete process of identifying the symptoms of a fault to the taking of appropriate corrective actions on a system to restore it to normal functioning state (Schaafstal, et al. 2000). It is a type of problem in the typology of problems on the continuum from well-structured to ill-structured problems (Jonassen, 2011). Other terms used interchangeably include debugging, maintenance or fault diagnosis and repair.

PHENOMENOGRAHY: a qualitative research approach that has been designed to find out people's qualitatively different experiences of the world in terms of categories of descriptions; "it is designed to answer certain questions about thinking and learning" (Marton, 1986). It could serve as a research methodology (comprising methodological and analytical framework) and theoretical framework.

PHENOMENOGRAPHIC ANALYTICAL FRAMEWORK: the innovative analytical framework component of phenomenography's research approach. The methodological strategy for data collection and analysis (Tight, 2016).

CATEGORY OF DESCRIPTION: a descriptive category of explanation, which characterises a conceptualization; it is an interpretation of another person's interpretation (Alant, 2011).

OUTCOME SPACE: the union of a set of categories of description; an abstract space made up of categories of description. The full range of possible ways of experiencing the phenomenon in question for the population represented by the sample group collectively (Åkerlind, 2012).

DIALECTIC: to compare and contrast different part of view or construct. In Lefebvre's theory, it implies comparing internal interactions among the three moments of space (Lefebvre & Nicholson-Smith, 2012, p. 60).

THEORY OF SPACE: the theory of production of space in Lefebvre's usage. The word production in Lefebvre's assumption is used by him in the sense of "the process of producing" rather than only the 'action' of inducing production (Lefebvre & Nicholson-Smith, 2012, p. 16). Lefebvre initially focused on the social production of the spaces within which social life takes place, and later extended his attention to the production of educational spaces. Three spaces considered in Lefebvre's triads are namely; the conceived space, the perceived space and the lived space (p. 53).

THE CONCEIVED SPACE: also variously referred to as the representations of space, the mental space, the space of imagination, distance or desired space, access or denial space, places of popular spectacle, the space of abstractness, the space produced by economic transactions and state policies (Lefebvre & Nicholson-Smith, 2012, p. 38)).

THE PERCEIVED SPACE: also known as the spatial practice, the spatial practice of a society 'secret' that society's space, the physical space, the common sense belief, personal space, passively experienced space (Lefebvre & Nicholson-Smith, 2012, p. 37). "It is a space that has close affinities to people's perceptions of the world, of their world particularly its everyday ordinariness, it structures lived reality, include routes and networks, patterns and interactions that connect places and people – it aids or deter sense of location and the manner in which a person acts". (Merrifield, 2013, p. 110)

THE LIVED SPACE: also called the spaces of representation, the lived and the endured space, the experienced concrete space, the directly lived space associated with symbols, the space of inhabitants and users (Lefebvre & Nicholson-Smith, 2012, p. 38).

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Although engineers solve a variety of problems in practice, such as design problems, system analysis problems, troubleshooting remains one the most common forms of everyday problems engineers solve (Jonassen, 2011). Electronics engineers debug computer programmes, diagnose design faults and repair electronics engineering equipment; all these tasks require troubleshooting skills (ibid). However, despite troubleshooting being regarded as one of day-to-day experiences of engineers, it is not explicitly articulated in the electronics engineering programme curriculum. This is reflected globally in the generic engineering graduates' skills requirements. The term 'generic engineering graduates' skills' applies to the competencies, attributes and skills that are important in an engineering career (Male, 2011). The generic skills are stipulated as standards in the policy documents and accreditation criteria for engineering education programmes of every country worldwide. For an example, the Accreditation Board for Engineering and Technology (ABET) is USA-based. The European Network for Accreditation of Engineering Education (ENAEE) is for European countries. The Institution for Professional Engineers New Zealand is for New Zealand, Engineers Australia (EA) for Australia and International Engineering Alliance (IEA) is for the worldwide engineering body. In Africa, the Nigeria Society of Engineers (NSE) is for Nigeria, and the Engineering Council of South Africa (ECSA) for South Africa (Male, Bush, & Chapman, 2010; Male, 2010; Ramadi, Ramadi, & Nasr, 2016).

All these organizations provide the standard for their engineering programmes. The latest criteria from US (ABET, 2018-2019) stipulates for these organizations 11 programme outcomes, which are generic engineering competencies. These are comparable to the whole international standards enshrined in the [1]Washington Accord Graduate Attributes. These generic engineering competencies do not explicitly emphasise troubleshooting as a skill required even among the so called technical competencies required for engineers. The focus on the place of troubleshooting in this study is used to trace empirically how electronics engineering troubleshooting fits into the discipline boundary of university electronics

[1] The Washington Accord Graduate Attributes were formulated by signatories from Australia, Canada, Chinese Taipei, Hong Kong China, India, Ireland, Japan, Republic of Korea, Malaysia, New Zealand, Singapore, South Africa, Sri Lanka, Turkey, United Kingdom and the United States of America (ECSA, 2017).

engineering professional policy, the electronics engineering curriculum, and practices of lecturers, laboratory technicians and students in an electronics engineering programme. The lack of a firmly delineated path of electronics troubleshooting skills within the literature undermines any attempt at trying to disrupt the already entrenched knowledge and skills which have developed solid and defined paths in university electronics engineering programmes. The aim of this study is to explore and locate the place of troubleshooting in an undergraduate electronics engineering education programme. The study, like Jonassen (2011), contends that troubleshooting has to be one of the most essential problems in the typology of problems that engineers are required to solve in principle and practice. It thus argues that engineering programmes, all over the world, ought to make provision for its inclusion and coverage in the curriculum content, pedagogy and enactment.

This chapter attempts to provide a review of related previous studies that identify relevant issues on the place of troubleshooting in electronics engineering education programme. The discussion in this chapter will be divided into six sections. Section 2.1 presents details on the arguments on the place and space of troubleshooting in electronics engineering education, section 2.2 describes troubleshooting generally, section 2.3 discusses the reasons for researching on engineering troubleshooting, inclusive of electronics troubleshooting. The remaining sections, 2.4. 2.5 and 2.6, present electronics the context of the troubleshooting skills, empirical studies previously conducted on troubleshooting and conclusions respectively.

2.1 Uncertainties on the place and space of troubleshooting in electronics engineering education

The troubleshooting skill, despite its neglect within many university programmes, is still integral and critical in science, technology, engineering and mathematics (STEM) disciplines (Johnson, 1995; Jonassen, 2011; Jonassen et al., 2006), inclusive of electronics engineering (Dounas-Frazer & Lewandowski, 2017). As reported by Dounas-Frazer and Lewandowski (2017), particularly in electronics courses, the ability to troubleshoot is always an important design-related learning outcome for undergraduate students. However, we are not certain about the extent to which the university engineering programme staff (lecturers and laboratory instructors) emphasise troubleshooting skills in the training of electronics engineering students. Furthermore, there is a need to investigate electronics engineering students' perceptions and experiences of troubleshooting in their training because troubleshooting plays a significant role in the activities of any engineering programme. This has also become necessary as troubleshooting is inadvertently missing in the statement of generic engineering competency skills in undergraduate electronics engineering competency requirements, as found in ABET and ECSA documents. As Male (2011) has rightly pointed out, design has carried a major glamour in engineering education; this has equally affected policy making in engineering training and accreditation requirements. Yet there are other aspects of engineering education such as troubleshooting, fault diagnosis and repair and equipment maintenance that are part of the training experience but hardly receive detailed pedagogical focus. Engineering practice has several tasks intertwined together that require proper coordination and harnessing of all the tasks to enhance the holistic training of engineering graduates. A proper realisation of all relevant tasks in engineering practice could help policy developers and educators explain the relevance of the coursework to students appropriately (Trevelyan, 2007). It could also help to provide appropriate motivation for students to learn all the requisite skills in preparation for future workplace experience. Such understanding may also reveal gaps in the curriculum and provide opportunities to improve curriculum design.

The literature reviewed seems to offer the following two different perspectives on the uncertainties of troubleshooting in engineering: practical versus theoretical engineering practice and task definition between engineers and technicians. These two perspectives are briefly discussed below in order to clarify the dichotomy that exists in engineering education programme.

(i) Practical versus theoretical engineering practice:

The divide between practical and theoretical engineering practice began after the introduction of science-based engineering programmes to replace the practice-based engineering programmes after the Second World War (Crawley et al. 2007). The science-based engineering programmes operate a theoretical university engineering curriculum that has differed from a practice-based curriculum, which can be described as a practical oriented university engineering education curriculum, found in what were referred to as polytechnics and later renamed as universities of technology (Kloot & Rouvras, 2017). This has thus created a dichotomy between practical and theoretical practice in engineering education globally. The graduates from science-based universities are seen as elite professional engineers who are taught basic engineering science and creative design, whereas the universities of technology graduates are referred to technologists who are taught practical engineering skills. In other words, the graduates from elite conventional universities of engineering (professional engineers) who have science-based training are regarded as being theory-based while those graduates from universities of technology (technologists) are regarded as being practical-based.

(ii) Task definition between engineers and technicians:

Jonassen and Hung (2006) argue that technicians view their job responsibilities as purely practical in nature, while engineers appear to be theoretical and design biased. Their argument is premised on the view that technicians see a lot of engineers who have theoretical knowledge, but little ability to apply this knowledge in technological problem solving and troubleshooting skill. Engineers seem to talk themselves out of making a decision as they are uncertain if they are right and are unwilling to test it (MacPherson, 1998). Flesher (1993), alongside with Jonassen and Hung (2006) report that the organisation of knowledge may be different in the case of the electronics troubleshooting tasks of technicians and of engineering experts, based on their typical application. Their arguments showed that maintenance technicians define their task as the search for a fault in a system which has previously operated properly. The designers (engineers in this case) on the other hand, define their task as understanding the basic function of the system, comparing conceptualizations to observation as their major concern. These arguments show the distinction and disparity observed between the roles and tasks of technician and engineers. From the foregoing review, it appears as if the context of troubleshooting in electronics engineering education has been shifted to belong to the electronics technicians while professional engineers takes the role of designers only. Hence, there is the need to clarify what constitute the meaning of troubleshooting and troubleshooting in electronics engineering context.

2.2 What is troubleshooting?

The word troubleshoot originates from “trouble” and “shoot”. Oxford Dictionaries defines troubleshoot as “analysing and solving” serious problems for a company or other organizations, to trace and correct faults in a mechanical or electronics system (Troubleshoot, n.d). The term “troubleshoot” means to find and solve technical problems and issues, to repair a malfunctioning apparatus (Dounas-Frazer and Lewandowski, 2017). Technically, troubleshooting is described as a series of processes which include; analysing the behaviour or operation of a faulty circuit to determine what is wrong with the circuit, identifying the defective component(s) and repairing the circuit (Rhude, n.d). According to Rhude, troubleshooting is a task that can be very challenging depending on the type of equipment, circuit or system. Sometimes diagnosing problems can be easy especially when the component(s) having problem is easily visible. At other times diagnosing can be difficult when the symptoms as well as the faulty component cannot be easily traced. Troubleshooting is about solving problems particularly in circuits or systems. If the defective component or part of the system has visual signs of burning, it would be easy to spot, whereas an intermittent problem caused by a high resistance connection can be much more difficult to find (Rhude, n.d.).

Troubleshooting could mean a process whereby you diagnose a malfunctioning system or circuit and identify the specific defect (Crismond, 2013).A more comprehensive definition, adopted in this study, is that which refers to troubleshooting as the complete process of identifying the symptoms of a fault to the taking of appropriate corrective actions on a system (Schaafstal et al., 2000). This definition gives a complete overview of the skills and types of knowledge used in troubleshooting process. Troubleshooting involves using procedures to isolate and identify what is wrong with a device that used to work and repairing or replacing that part or subsystem to fix the device (Crismond, 2013). In troubleshooting, including within electronics systems, an attempt is made to figure out the faulty states in a system and repair or replace the faulty components properly in order to restore the system to normal functioning (Jonassen& Hung, 2006, Jonassen, 2010).

To be effective in troubleshooting requires checking a circuit or system behaviour against your expectations, one by one, until you find one that does not match (Johnson, 1995). Hence, troubleshooting is most commonly a cognitive activity that usually includes the search for likely causes of faults through a potentially enormous problem space of possible causes (Schaafstal et al., 2000). The main emphasis in troubleshooting, electronics inclusive is on fault diagnosis and detection, either in circuit, system, device or much larger in an equipment, which involves a search for the components of the system that are not producing standard or expected outputs (Jonassen & Hung, 2006). Hence, the major function of trouble-shooters is to search for actions that will efficiently eliminate the discrepancy in system performance.

2.3 Why troubleshooting?

Studies have revealed that there are various reasons for studying troubleshooting. For instance, Ottosen (2012, p. 3) highlights three reasons for conducting a formal study of troubleshooting. The first reason, according to this scholar, is that problem solving tasks take up huge amounts of work hours worldwide. For some people, it is their job, and for other people, it is a constant annoyance hindering their real job. Whether accepted or rejected, problem solving is a continuous or daily affair; no single system, machine or equipment is perfect or will constantly maintain a perfect condition. The second reason is that troubleshooting enables a structured approach to problem solving. Making attempts to solve emerging problems by using ad hoc approaches such as "trial and error" makes the process of problem solving slow, solutions are easily forgotten over time and one may end up starting from the scratch again. A structured approach is required to bring to the fore previous solution heuristics, reused and improved upon. In other words, a formal approach helps to prevent loss of past problem-solving methods which can be recalled and reused or improved upon in another similar problem situation. Lastly, Ottosen added that problem solving tasks are difficult. The simpler the problem, the easier the solution path, the more complicated the problem, the larger are the potential benefits of providing a formal approach to solving the problem. Regardless of how complicated the problem is, there is great potential for optimizing the problem-solving skills by structuring, reusing and improving existing knowledge.

Troubleshooting is therefore considered an important skill for engineering careers. Dounas-Frazer and Lewandowski (2016) assert that engineers need to be interested in troubleshooting because the requirements for some of their projects are so challenging and difficult that the final product does not work as expected, at least not for the first time. They further argue that for any experiment, design or project work in electronics there is an expert guide about the phenomenon of troubleshooting. The guide assumes that (a) engineering students should always expect to troubleshoot (b) circuit-building activities provide opportunities for engineering students to troubleshoot, and (c) students' ability to construct functional circuits can be a proxy for their ability to troubleshoot malfunctioning circuits (Dounas-Frazer & Lewandowski, 2016, p 1). These assumptions are premised on the reality that, in most cases, nothing works for the first time in laboratory works. Though students sometimes build circuits that function correctly without a need to troubleshoot, most circuit building processes would require troubleshooting before completion and implementation. However, students' efficiency and their successful completion of laboratory, individual or group projects can be affected by other factors aside troubleshooting. In electronics manufacturing, Pease (2013), an analogue circuit legend, reports that the fraction of manufactured items that fails to function in industry when power is first applied ranges from 20% to 70%. This fraction may sometimes fall as low as 1% and rise as high as 100%. Pease (2013) further emphasizes that, on average, production engineers and technicians must be prepared to repair 20%, 40% or 60% of the complex units of production. His argument goes further that if engineering products are manufactured in batches of 100, engineers should not be surprised to find some batches with 12 pieces that require troubleshooting and other batches that have 46 of such pieces.

According to Peace, the troubleshooting of a new product may be tough especially when the solution part has not been worked out (ibid. 2). It might even be tougher when the design is old and the parts of the circuits it now uses are quite different to those it used before. Troubleshooting can be tougher still when there is not much documentation describing how the product is supposed to work, and the designer or manufacturer could not be reached any longer. In Pease's opinion, if there is ever a time when troubleshooting will not be needed in engineering profession, it is just going to be a temporary solution. From this scholar's narrative, therefore, it is obvious that troubleshooting may be overlooked for a while; its skill cannot be overemphasized in engineering profession. This suggests that troubleshooting is often required in engineering practice. Troubleshooting skills and not only design skills are essential for engineering training, hence the need for them to be seen as an essential part of the engineering education curriculum.

Whether designing or developing, implementing or producing, maintaining or repairing phases, troubleshooting will be a significant skill for electronics courses and careers. Each of these phases has a distinct goal-related structure. Flesher (1993) reports that problems that occur in the design phase are novel presentations that require the development of new knowledge and structure. Problems in the implementation phase require application of a known process or production of a viable design, whereas problems in the maintenance phase require continuation of a specified standard, through adherence to a conceptual structure or pre-determined physical condition. Dounas-Frazer and Lewandowski (2017) equally note that an important aspect of troubleshooting in electronics courses involves revising the design of a circuit, not just its physical condition or construction. In electronics courses that engage students in laboratory work that involves designing circuits and building circuits, there could be a discrepant circuit performance due to a design flaw, in addition to a faulty component or errant connection which will require troubleshooting. In most cases, electronics students engage in design and construction troubleshooting phases, which should actually prepare them for other phases of troubleshooting proficiency. Furthermore, Dounas-Frazer and Lewandowski (2016) suggest that developing students' ability to troubleshoot should be one of the central goals for electronics courses.

2.4 Electronics troubleshooting skills

Troubleshooting is among the most common electronics skills (Pease, 2013). The task of maintaining modern electronics equipment and devices requires the ability to diagnose faults and repair the faults – troubleshoot. Electronics troubleshooting can be done on a mechanical device, electronic or electrical system. The purpose is solving a problem or checking the misbehaviour of the system against expected behaviour until the fault is located and rectified. Whether a faulty electric motor, AC/DC machine, transformer, power generation or transmission system, communication system, refrigeration or air conditioning system, troubleshooting will attempt to check the circuit behaviours one by one to isolate the faulty state in order to restore the system back to normal functioning (Jonassen & Hung, 2006). The word diagnosis is sometimes interchangeably used for troubleshooting and has been defined in different ways in literature. Sometimes, diagnosis is singled out to mean the process of identification of the symptoms to the determination of the fault (Schaafstal et al., 2000). In other times, while particularly referring to troubleshooting, the entire process of symptom identification, fault determination, and compensatory actions is taken into consideration (ibid. p. 1).

An electronics system consists of a number of interrelated electronic components and modules, cards, shelves, racks or cabinets, forming a collective entity, fixed in place, and involving interconnecting cables. Sometimes, it may also involve mechanical or electromagnetic components. According to Crismond (2013), in order to achieve standard diagnostic and repair work on an electronic unit, it must involve: firstly diagnosis and repair of the system or equipment to module level, and secondly, the use of test instruments to identify faults, measure and adjust equipment and confirm proper performance. Crismond (2013) also suggests typical instruments that a troubleshooter must be able to manipulate properly to include multimeters, oscilloscopes, signal generators, and signal tracers. More advanced or specialised instruments may be required depending on the nature of the equipment. The task of troubleshooting is described as a bridge that connects engineering design and scientific inquiry (ibid. p. 5). Crismond (2013) further emphasized that, to troubleshoot effectively, students need to know and use many concepts from science, technology, engineering, and mathematics disciplines as well as have knowledge of materials, construction techniques, and tools for exploring the devices, including mathematical models. Dounas-Frazer and Lewandowski (2017) indicate how troubleshooting is conducted, particularly in electronics courses. There are a few steps that are often involved in troubleshooting electronic circuits, which should be in specific order, as highlighted by these authors. The first step is to identify the symptoms of defect in the faulty circuit to figure out the cause(s) of the problem. The second step includes fault analysis and determination of the possible causes of the fault. If the problem seems to be difficult or appears new to diagnose, the proficient novice troubleshooter asks for help from both student and instructor. The final step is fixing the problem and testing for expected performance. The troubleshooter finally gets the circuit to work.

In the first instance, it is essential to identify and recognize the symptoms in the defective circuit. A defective circuit is one where the output parameters are incorrect, although the input parameters are correct. Once the symptom is identified, the reasons that cause it have to be determined. For an example, in a typical amplifier circuit, if the input signals of the amplifier is correct but there is no output or bad output is measured, the possible symptom is lack of voltage at the output. Sometimes, a particular symptom may not provide much information about the possible causes or defect. The failure of various components in the circuit may result in the same symptom. In other cases a particular symptom points directly to a certain area where the fault is most likely to have occurred. The choice of which of several methods to use depends on the circuit complexity, symptoms and personal preference of the troubleshooter. The basic electronics troubleshooting techniques for identifying the symptom and the cause of a fault, as highlighted by Industrial Development Corporation Technologies (IDC) in their document on practical troubleshooting and problem solving in electronics circuits (IDC, 2016, pp. 230-231), are listed below:

(i) Power check: Most often, the simple cause of circuit malfunction is power failure, lack of sufficient power or no supply of power. The supply power cord may be faulty, it may be a blown fuse or unregulated power supply. Sometimes the voltage level at the output of a power supply rectifier of a circuit may be connected with incorrect polarity.

(ii) Visual inspection: Visual inspection is a sensory check that relies on the visual senses to detect a possible fault. By visually inspecting a printed circuit board (PCB), half of the causes of fault(s) can be identified or detected. This could reveal a bad soldered joint, burnt components or an overheated component.

(iii) Using a sense of touch: This is another sensory check. Overheated components can be detected by simply touching them. It is a very useful troubleshooting technique in circuits, where everything seems to work properly for a while, and then the circuit fails due to overheating of certain components. Identifying such components helps to detect the possible cause of the fault. Special freezing sprays are also available, which allow instant freezing of components once they have overheated.

(iv) Smell check: When certain components fail due to overheating, it is possible to detect by a smell of smoke, especially if one is there at the time the accident occurred.

(v) Component replacement: This method relies mostly on the operator's skill and experience. It is a good troubleshooting technique for an experienced troubleshooting technician or engineer.

(vi) Signal tracing: This technique is the most desirable as it requires intelligent and logical thinking from the troubleshooter. The method is based on measuring input and output signals at various test points along the circuit. A test point in the circuit is the point where the value of the voltage is known. Once a discrepancy occurs at any point, the troubleshooter will know that problem exists in that portion of the circuit.

Dounas-Frazer and Lewandowski (2017) argue that both cognitive and non-cognitive characteristics of troubleshooting proficiency as well as circuit construction practices are critical characteristic of competent troubleshooters. A study conducted by Dounas-Frazer and Lewandowski (2017) explored electronics laboratory instructors' approaches to troubleshooting instruction. The results indicate that some experts believed that students can learn troubleshooting while some disagreed, and hold that some aspects of troubleshooting proficiency are innate. Dounas-Frazer and Lewandowski (2017) highlight cognitive aspects associated with troubleshooting, including, among others, mastery of multiple types of knowledge, cognitive subtasks, and strategies. Confidence, patience, independence, emotional regulation and attitude were identified and verified as hallmarks of non-cognitive proficiency in electronics troubleshooting (ibid. 14).

2.5 Empirical studies on troubleshooting in electronics and related engineering programmes

The notion of troubleshooting in engineering education, and particularly in electronics engineering, has raised some issues of concern as to where it belongs in the programme. This is coupled with the dichotomy between theory and practice in engineering programmes. These issues require a review of previous work to highlight various developments around the problematics of troubleshooting in electronics engineering education. To this end, the following sections report relevant literature that underpins the relevance of troubleshooting in electronics engineering education programmes. The reviewed literature demarcates previous research that relates to the present study in context and coverage.

2.5.1 Troubleshooting in engineering education

Ottosen (2012) researched "solution heuristics for troubleshooting with dependent actions and conditional costs" in Denmark, Europe. The study revealed that problem solving tasks take up huge amounts of work hours worldwide, therefore troubleshooting, which is a type of problem solving in the engineering profession, requires a structured approach whereby previous efforts are saved, reused and improved upon. The study further revealed that problem solving tasks in electronics engineering are difficult and computers are far better than humans for optimizing these tasks, however, human intelligence is required for efficiency.

Male et al. (2010), in their qualitative study in Australia on the perceptions of competency deficiencies in engineering graduates, investigated the unfolding changes in engineering graduates' competencies as perceived by engineers. Findings from the study revealed that problem solving, which comprises troubleshooting problems, the ability to apply engineering knowledge to design and critical thinking are among the competencies graduates engineers lacked. In a related study that draws lessons from engineering educators on everyday problem solving in engineering, by Jonassen et al. (2006), problem-solving has been regarded as an essential skill for engineering workers. The study reported that troubleshooting problems are among the key problems skilled engineering workers solved. The workplace problems are solved by dependence on the workers' experiential knowledge, as they recall conceptual knowledge developed in their school experiences. Another study by Passow and Passow (2017) sought for the competencies that should be emphasised for undergraduate engineering programmes among generic engineering competencies. The study revealed that problem solving is core for all engineering practice. While comparing engineering competencies that are important for all engineering disciplines, problem solving, communication and team work were rated top level competencies among others. Despite the significance of problem solving, notwithstanding, if the relevance is not maintained and well attended to through a balance in institutional training on theory and practice, a significant lack of this competency will continue to exist within the domain of engineering education programmes. Comparing the studies by Male et al. (2011) and Male (2010), it was noticed that low status has been assigned to generic engineering competencies that are required by professional engineers across all engineering disciplines in Australia, Europe, New Zealand, and the USA. Even then, these competencies do not include troubleshooting skills among the required competencies for careers in engineering.

In another study by Passow (2012) that sought the opinions of engineering graduates on which of the competencies are important for professional practice, the study showed that problem-solving, data-analysis, teamwork and communication are among the top-cluster competencies that are most deemed important by engineering graduates of 11 engineering majors, electronics inclusive. The study further suggested that faculty members should work with advisory boards and employers on the design and development of an engineering curriculum that should consider placing special emphasis on these "top cluster" competencies. Furthermore, Lord (2010, p. 45), commenting on problems encountered with engineering education programmes designed by ABET on important competency skills, asserted that there is a big gap between what engineers do in practice and what the faculty members think they are preparing them for. This suggests that there is a gap between typical engineering curricula and competencies acquired in preparation for engineering workplace practice.

Furthermore, a study by Spinks, Silburn and Birchall (2006) on "educating engineers for the 21st century: the industry view," attempted to identify skill gaps in the early years of a graduate engineers' career in the United Kingdom. The results of the study highlighted practical application and technical breadth among the weaknesses that fresh graduates manifest. In contrast, strong points were recorded on team-working and theoretical understanding. The culture of practical application and technical skill still remains one of the core aspects of engineering which are required in the workplace.

2.5.2 Studies on evaluating the effectiveness of various instructional strategies on troubleshooting

Van Gog, Paas and van Merrienboer (2008), from the Netherlands, conducted research in an experimental study which compared the impact of sequences of process-oriented and product-oriented worked examples on the troubleshooting transfer of electrical engineering students. Two types of sequences were involved: the product-product or process-process sequence and product-process or process-product sequence. The purpose was to determine which sequence lead to higher efficiency on troubleshooting transfer taska. Findings from the study revealed that process information might initially impose an effective cognitive load and lead to higher efficiency in electrical circuits troubleshooting, yet may become redundant and impose an ineffective load when training progresses. This may hamper efficiency. The study highlighted the efficiency of a sequence of learning that can improve electrical circuits troubleshooting. This approach could be regarded as a theoretical approach to troubleshooting instructions in engineering. Such training requires a further solid foundation for practical use of the sequences in other to acquire the requisite complex troubleshooting skills.

In another study conducted by Van De Bogart, Dounas-Frazer, Lewandowski and Stetzer (2015) in Colorado (USA) on the role of metacognition in electronics troubleshooting, the study unfolded the various ways students proceed when diagnosing and solving electronics problems. The study established that the role of metacognition, whereby students are assisted in making meaningful informed decisions, cannot be overemphasised and that it is an important component of effective troubleshooting.

In the exploratory study of Srivastava and Yamnniyavar (2018) in Singapore, on embedded intelligence as a means of minimizing cognitive load of students in electronics engineering instructional laboratory sessions, it was asserted that students experienced frustrations due to faulty equipment and troubleshooting problems. This is due to an inability to debug circuits and a lack of theoretical and practical knowledge. According to these scholars, it was noticed that the students' difficulties in electronics laboratory works emanated from complicated circuits, faulty equipment and debugging of circuits. The faulty equipment consumed time as debugging became difficult as the students applied trial and error based type for debugging (Srivastava & Yamnniyavar, 2018). Estrada and Atwood (2012) added that most of the time, frustration is experienced because the experiments were performed on trial-and-error basis by the students which invariably reduces the learning components, which is the very purpose of the experiment being part of the curriculum.

Dounas-Frazer and Lewandowski (2016) in USA investigated the concept: "nothing works the first time: an expert experimental physics epistemology". The outcome of the study revealed that troubleshooting is an important learning goal for electronics courses. Students' ability to troubleshoot is a critical skill for physicists and engineers. Furthermore, the study revealed that instructors' teaching practices seems to be influenced by the underlying belief that "Nothing works the first time", that is electric circuits would not work as intended immediately after they are constructed, hence troubleshooting is required on most laboratory activities. Therefore, students offering electronics courses are expected to anticipate knowing how to troubleshoot. The notion of possibilities of fault should reflect in institutional curriculum and instructions, and there should be provision of basic structure for electronics students to troubleshoot. Furthermore, the policy on electronics engineering courses should ensure that troubleshooting attributes are included in the curriculum and instruction.

Another study by Van Gog, Paas and Van Merrieboer (2006), also in the Netherlands, investigated the effects of process-oriented worked examples on troubleshooting transfer performance in the domain of electrical circuits. This work differs from and precedes the research by the same group of authors, who latter investigated the effects of studying sequences of different worked example models on troubleshooting transfer. The aim of this study was to find out whether process-oriented worked examples would lead to better transfer performance than solving conventional troubleshooting problems, with less investment of time and mental effort during training and testing. It further sought to find out whether adding process information (in this case, a single model) to worked examples would increase the investment of effort during training and enhance transfer performance. The first hypothesis was confirmed. The second hypothesis was not. Findings from this study indicate that implementing more support in the form of worked examples in troubleshooting instruction would make that instruction more effective, lead to transfer performance that would be both better and more efficient (i.e. better performance is obtained with less investment of time and effort by novice learners). The study revealed that theoretical troubleshooting worked examples enhances better transfer performance. This establishes the notion that electronics students who are novices could be given practical troubleshooting instruction, as this could improve their performance and also strengthen the transfer of skills to workplace practice.

Kester, Kirschner and Van Merrienboer (2006), in the Netherlands, conducted a study on "just-in-time information presentation: improving learning a troubleshooting skill". The study examined two-types of information required for troubleshooting in a [2]practice situation, namely, declarative information (problem-cause for finding an adequate solution) and procedural information (for manipulating the environment). Findings revealed that it is better to present the declarative information and the procedural information piece-by-piece instead of doing so simultaneously, so as to realise an improvement in the learning of troubleshooting skill.

A study was conducted by Kester, Kirchner and van Merrienboer (2004) on information presentation and troubleshooting in electrical circuits. It was aimed at investigating the optimal timing of information presentation that could facilitate learning and enhance test performance

---

[2] Practice situation is the period before and during the troubleshooting task (Kester, Kirschner & Van Merrienboer, 2006)

in troubleshooting. An optimal information presentation format was proposed. The format consisted of supportive information presented before practising a troubleshooting skill and procedural information is presented during the practice of troubleshooting in electrical circuits. Results from the study indicated that it is possible to determine the optimal information presentation for the [3]four types of simulation practical used on task requirements. The distinction between supportive information and procedural information proved useful to distinguish between different optimal moments for presentation. The implication is that students experience less stress when searching for the right information in problem solving tasks when the information needed to support them in handling the troubleshooting task is presented at the right time. In other words, supportive information should be supplied just before it is needed for practice while procedural information can be supplied directly during practice.

2.5.3 Studies on training programmes and models for students on troubleshooting

Hochholdinger and Schaper (2013) conducted a quantitative quasi-experimental design study on "training skills with an anchored instruction module in an authentic computer-based simulation environment". This study further corroborated the work of Van Gog, Paas and Van Merrienboer (2007) and Van Gog, Paas and Van Merrienboer (2006) on the possibilities of transferring the skills of troubleshooting. It was researched to improve the application and transfer of troubleshooting skills when diagnosing faults in complex automated production units. The anchored instructional module is a video-based simulation package used during the instructional process. It took the form of illustrated problem-based sequences of troubleshooting in a collaborative learning setting. It complemented individualised problem-solving tasks in a simulation environment. The effects of the anchored instructional module on 42 mechatronic apprentices were evaluated. Findings showed that such anchored instructional modules have a positive impact on the success of apprentices' diagnostic skills, especially in the near transfer and content transfer task environment. This study tends to foreground that training on troubleshooting skill can be reinforced in electronic engineering through a simulated environment. Students who learn or experience troubleshooting in their activities in such electronics courses require a variety of simulation reinforcement.

[3] These comprised two supportive information task simulations (before or during task practice) and two procedural information task simulations (before or during task practice) (Hochholdinger & Schaper, 2013).

Another study was conducted by Dounas-Frazer, Van De Bogart, Stetzer and Lewandowski (2016) in Colorado, USA, on the role of modelling in undergraduate electronics troubleshooting. The study used model-based reasoning on a troubleshooting task with data collected in think-aloud interviews during which pairs of students attempted to diagnose and repair malfunctioning circuits The study revealed that the use of an experimental modelling framework on students' troubleshooting tasks, using data collected in think-aloud interviews during which pairs of students attempted to diagnose and repair a malfunctioning circuit, informed explicit instruction and assessment of troubleshooting skills in electronics courses The study showed that students working on a troubleshooting task can be mapped onto an experimental modelling framework, showing the significance of modelling for electronics engineering troubleshooting.

Attia, Tembely, Hobson and Obiomon (2018), also in the USA, investigated the use of "hands-on" tools to change the learning style in the engineering classroom to more engaging teaching pedagogies. The study reveals that troubleshooting is one of those skills students could master through multiple exposures to hands-on learning of electrical components and electronics devices. The study further showed that teaching lab skills such as bread-boarding and troubleshooting are regarded as some of the knowledge and skills students gained from electronics engineering courses. This indicates that troubleshooting is significant for students learning in electronics engineering education and should reflect in both the curriculum and instruction of practical laboratory electronics engineering programmes tasks.

Pate, Wardlow and Johnson's study (2004) in Arkansas, USA experimented on the effects of thinking aloud pair problem solving on the troubleshooting performance of undergraduate agriculture students in a power technology course. The experimental study was conducted to determine the effect of such problem solving on the troubleshooting performance of these students. A think aloud pair problem solving (TAPPS) training approach affords assigning a listening partner to the participants while the participants verbalise their thought processes during the process of troubleshooting. Findings from the study showed that think aloud pair problem solving may be an important step in the development of metacognitive skills among students in technological troubleshooting. However, how the practices promoted by this finding are different from typical practices in electronics troubleshooting remains unclear. In fact, technological troubleshooting as defined by MacPherson (1998) refers to technical troubleshooting, which is a special category of problem solving. This implies troubleshooting could be emphasised as a technical hard-core engineering skill.

Ching-Zon, Ching-Fang, Huang and Chang (2004), in Taiwan, conducted a study of thinking processes in the troubleshooting of single-chip microcomputer system. Three major objectives were set for the study. The first was to explore successful factors of troubleshooting diagnosis in single-chip microprocessors. Secondly, to analyse the thinking processes in the troubleshooting of single-chip microprocessor circuits and thirdly, to design the diagnosis processes of troubleshooting in single-chip microprocessor circuits. Findings revealed that the study provided a form of teaching model for troubleshooting single-chip microcomputers. The study also presented valuable troubleshooting strategies, process, and methods for both national and international academic fields. Furthermore, the study highlighted some successful factors of the diagnosis processes of troubleshooting in single-chip micro-processor circuits as professional knowledge, comprehension for circuits, fully taking advantage of strategies, wisely making use of electric meters, judging and defining qualities of components and using sensory assessment.

Van De Bogart (2017) in Maine (USA) investigated extensively student learning of analogue electronics. The study examined three broad components. The first component broadly investigated student learning of specific classes of analogue circuits across physics and engineering programmes. The second component was an in-depth study of student understanding of bipolar junction transistors and transistor circuits, and lastly, a detailed study of the practical laboratory skill of troubleshooting of analogue electronics circuits. Significantly, the third component describes how students navigate through the task of troubleshooting in electronics, foregrounding the importance of collaborative regulation in such an endeavour. The findings on the third significant component showed that students did engage in one another's ideas while troubleshooting, and that instances of such engagement often helped students to better justify their choice of action, either by building more sophisticated predictions or by rejecting insufficiently justified hypothesis. It further confirmed that socially mediated metacognition improves the process of collaborative troubleshooting. These findings corroborate with the finding of Dounas-Frazer, Van De Bogart, Stetzer and Lewandowski's (2016) on the significance of metacognition in articulating troubleshooting learning process. Thus, students' troubleshooting skills can be significantly improved through mediation from others.

Researchers have explored troubleshooting in other fields of engineering aside from electrical, electronics and computer engineering programmes. For instance, Vigil, Miller, and Sloan Jr (n.d.) conducted a study on structured troubleshooting in process design for chemical engineering students. It was a study that aimed at adding a series of structured troubleshooting exercises and a simplified problem-solving methodology to a process-design course to help students acquire improved experience at hands-on process problem solving. The research stressed that troubleshooting experience could be integrated into engineering design course process; this would stretch students' skill and increase their troubleshooting proficiency. Vigil, Miller, and Sloan Jr (n.d.) further argued that a troubleshooting exercise could be introduced into design course mainly for two goals, firstly, providing students with a structured problem-solving strategy they could use after graduation, and secondly, to familiarize students with detailed troubleshooting techniques for important unit operations. Introduction of such experience into the traditional pedagogy of engineering design is capable of helping students to formulate a personal library of information they can store for future use and technical experience to solve real-world troubleshooting-related problems when they begin their engineering careers (ibid.). Such structured procedure could prepare students to solve a wide variety of troubleshooting problems different from the theoretical problem-solving approach during teaching and training process. The study revealed that troubleshooting could be an explicit part of any engineering curriculum. It is an indication that troubleshooting as part of engineering education is practicable in other aspects and disciplines of engineering.

Furthermore, Ross and Orr (2009) conducted a study on the teaching of structured troubleshooting as a way of integrating a standard methodology into an information technology programme. The study aimed at developing a standardised methodology to determine the effectiveness of a structured troubleshooting problem-solving approach in college students in the information technology (IT) field. As earlier reported by Ottosen (2012), Jonassen and Hung (2006) and Vigil, Miller, and Sloan Jr (n.d.), troubleshooting can be taught through structured methodology. Such structured methodology could be presented as a simple model or flowchart that provides a guide for troubleshooters. The standardised troubleshooting methodology termed DECSAR was created and integrated into the standard curriculum of a college information technology programme and components of troubleshooting were measured using a pre-/post testing approach with the social problem-solving inventory approach. Findings indicated that there was an improvement in several areas of troubleshooting such as problem definition, problem formation and generation of alternative solutions; student scores were increased by DECSAR. DECSAR has thus further provided evidence in favour of structured troubleshooting in both technical and non-technical aspect of problems.

The above review shows that troubleshooting has been studied in the context of electronics engineering programmes, instructional strategies on troubleshooting and models for troubleshooting practices. The non-inclusion of troubleshooting in engineering education policy has also been established. However, it has, firstly, never been studied in a context that is seen as contested in Lefebvre's theory and, secondly, in a context that is seen from multiple lenses. While there are several studies reviewed on troubleshooting on a range of contexts, there appears to be no work or not much work on the place of troubleshooting in electronics engineering programmes. None of these studies have explored the place of troubleshooting in engineering education as a contested space as advocated and argued by Lefebvre. In all the studies explored as reviewed in this chapter, troubleshooting is looked from only one lens, whilst the present study looked at the place of troubleshooting through three different lenses viz, the electronics engineering students, the lecturers, technicians, curriculum and policy. These spaces in Lefebvre's theory of space are referred to as the Lived space (students), the Perceived space (Lecturers, technicians and the curriculum) and the Conceived space (the policy). This study uses Lefebvre's theoretical lens to explore the contested space of troubleshooting in electronics engineering education programmes.

2.6 Conclusion

This chapter has presented the review of relevant literature on the context of troubleshooting in engineering education. The review foregrounded the point of departure of the present study from past research on the context of troubleshooting in electronics engineering which is underpinned by exploring through different theoretical lenses using the Lefebvre's theory of space and place. The next chapter presents the theoretical framing that helps to view the study.

CHAPTER 3

ANALYTICAL & THEORETICAL FRAMEWORKS USED IN THE STUDY

3.0 Introduction

The previous chapters have provided the background and the need for this study. Chapter 1 presented the contextual background whereby the problem of the study is being unpacked. Following this, chapter 2 presented the review of literature which locates the gaps in the place of troubleshooting in electronics engineering education programme in reviewed literature, necessitating an empirical exploratory study. As asserted by Osanloo and Grant (2016), a theoretical framework is required in research to provide a grounding base, an anchor for methods, analysis, interpreting and inferencing the results of the study, and most importantly, as a lens for theorising the findings of the study. Theoretical framework also provides the structure to define the methodological and analytical approach to the study as a whole (ibid.).

This chapter presents a detailed structure and overview of the analytical and theoretical frameworks carefully selected to underpin the study. The analytical framework drew on the phenomenographic perspective, while the theoretical framework adopted the Lefebvre's theory of space. This chapter will naturally be divided into two sections to unpack the two frameworks. Section 3.1 describes the phenomenographic framework in the light of the main constructs comprising the structural and the inferential aspects. The inferential aspect describes how research question one will be analysed and answered. The structural aspect is sub-divided into the two arms of the internal and external horizon. The internal horizon presents how research question two will be analysed and answered while the external horizon presents how research question three will be analysed and answered. Section 3.2 presents Lefebvre's theory of space, comprising the varied sub-sections to bring into focus the constructs in the theory and its relevance on educational research, the theory model and its application in the present study. The theory intends to provide answer to the critical question of the study.

3.1 The phenomenographic analytical framework

Phenomenography is a field of inquiry that provides qualitative researchers with experiential descriptions of the phenomenon under study (Marton, 1986). According to Marton (1981), phenomenography was originally developed from an educational framework by Ference Marton and co-research group in the Department of Education, University of Gothenburg, Sweden. It was designed as research approach to answer certain questions about thinking and learning. The word “Phenomenography” was coined in 1979 but started appearing in publications two years later (ibid). Marton viewed it as a content-oriented and interpretive way of describing qualitatively different ways in which people perceive and understand their reality. The aim of developing this approach in research is to describe, analyse and understand experiences in qualitatively different ways in an empirical manner (Bowden, 2000; Marton, 1986). This is what differentiates phenomenography from phenomenology.

A phenomenological study basically describes the meaning for various participants of their lived experiences of a phenomenon (Creswell, 2017). The focus is on describing what the participants have in common as they experience a phenomenon, it reduces individual experiences with a phenomenon to a description of the universal essence of it. Phenomenology differs from phenomenography in that it deals with first-order perspective, while phenomenography deals with second-order perspective of a phenomenon (Marton, 1981). The first-order perspective deals directly with what is experienced about a phenomenon and not how the phenomenon is experienced in varieties of ways by the participant (i.e. the learner) as is the case with the second-order perspective in phenomenography. In phenomenological investigation and analysis, the concern is the meaning that people give to the lived world and their everyday experience without dealing with the thought of that which is lived (Larsson & Holmstrom, 2007)

The present study seeks to understand the place of troubleshooting in the electronics engineering programme. It is intended to explore the perceptions of the electronics engineering policies, institutional curriculum and instruction and fourth year electronics engineering students on the place of troubleshooting in electronics engineering programmes. The study addresses the three research questions posed (see Section 1.4) by exploring how the stakeholders experience and enact troubleshooting differently in the programme and what informs how the phenomenon of troubleshooting is being experienced and taught in the programme.

To explain further the meaning of a ‘second-order perspective’, phenomonography adopts this an experiential perspective in which the interest is not to describe things as they are, but rather things are characterised by the process of perception and thought, by focusing on conceptions of specific reality and the contents of thoughts. (Marton, 1986, p. 32). In a phenomenographic approach, the different qualitative ways of people’s understanding, conceptualisation, interpreting and perception of a given phenomenon under investigation are described in detail. The focus of such details is to produce two distinctive outcomes of the phenomenographic study, namely, the emerging categories of description and the outcome space of the study (Marton, 1981). The categories of description represent the different ways of experiencing, or being aware of the phenomenon under study. These are used to facilitate the understanding of concrete cases of the study based on the conceptions of a specific reality. The categories bring several individuals' conception of a phenomenon into reliable terms that sufficiently describe the object well. Marton (1981) further added that the categories denote forms of thought of the respondents, which are brought together in order to characterise the perceived world, in the case of this study, the phenomenon of troubleshooting. The outcome space on the other hand describes the relationships and interactions between categories. The outcome space consists of a number of categories of description which depict the relationship between these categories, generally forming some type of hierarchical structure (Marton, 1981). It is the secondary outcome of research findings.

In this study, the respondents represent troubleshooting in different ways in a university electronics engineering programme which depicts the full range of possible ways of experiencing it in the entire programme. Their responses were collectively put together as the outcome space. The proven contribution of phenomenography to educational research, as seen in Alant (2001) and described by Marton and Booth (2013), makes it an ideal method for this study. In the context of the place of troubleshooting in electronics engineering education, the phenomenographic approach reveals the variation in the ways lecturers and laboratory instructors perceive and enact troubleshooting and the ways students experience the act and skill of learning how to troubleshoot. In exploring a research problem using phenomenographic framework, Marton and Booth (1997) advise that we consider two aspects in our analysis: the referential and the structural aspects of the ways of experiencing a phenomenon. The framework is presented in the figure below:

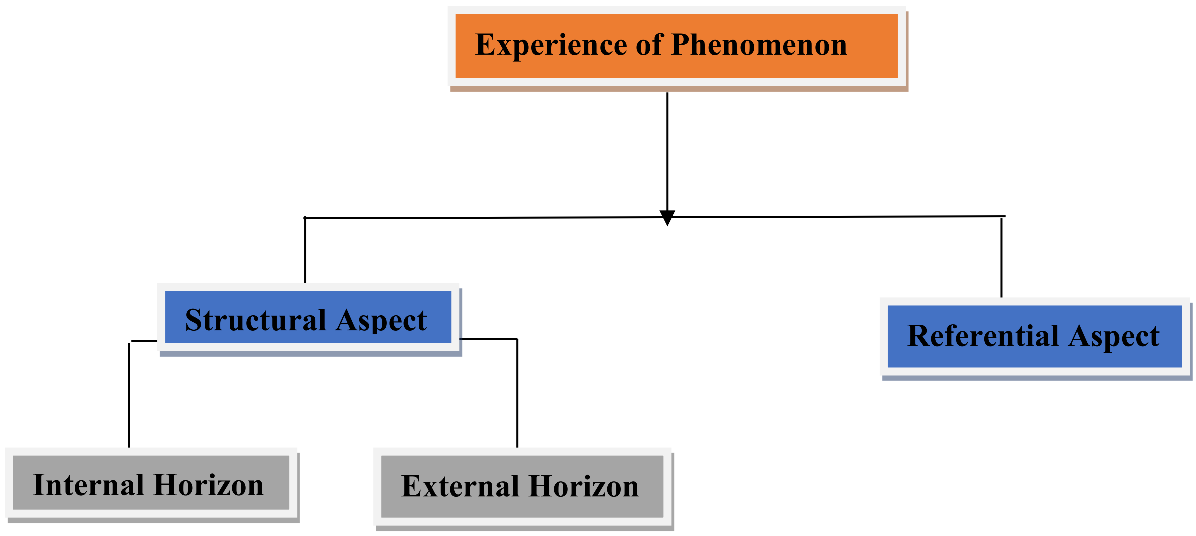


Figure 3: Component of phenomenographic experience (Adopted from Marton & Booth, 1997, p. 88)

3.1.1 The referential aspect

The first aspect of the phenomenographic analytic framework, the referential aspect of experiencing a given phenomenon, is described as highlighting the direct object of the phenomenon, giving it a particular meaning based on the way it is experienced (Marton & Booth, 1997). This is the overall meaning attached to the phenomenon, which in this study implies the place of troubleshooting in the electronics engineering programme. In phenomenographic research, the referential aspect always answers the question “what” on the direct object of learning, giving the overall meaning and perception of a phenomenon (Khan, 2014). The “what” question addresses the particular meanings, the general understanding of the object of study. This aspect goes with research question one which seeks to understand the “what is the place of troubleshooting” in an electronic engineering programme, as perceived by relevant stakeholders.

3.1.2 The structural aspect

The structural aspect is defined as how people act towards something, practise something, how they go about to carry out something, how something is acted upon (Marton et al., 2004). In the present study, it refers to how troubleshooting is being enacted and practised in an electronics engineering programme. In the same vein, what informs the act, the intention responsible for the act, is unpacked by this aspect. The structural aspect of an experience is further divided into two aspects: the external structure and the internal structure of an object. These are referred to as external and internal horizons (Marton & Booth, 1997, p 88).

3.1.2 (a) The internal horizon

The internal horizon of the way of experiencing a particular phenomenon is to discern the parts of the phenomenon of study, how the parts are interrelated as a whole object (Marton & Booth, 1997). This is how different parts of the phenomenon are brought together, experienced and enacted. The internal horizon answers the "how" question. It answers the second research question of the study on how the electronics engineering programme is enacted. The internal horizon of the structural aspect directly deals with the different ways and strategies of enacting troubleshooting in electronics engineering programmes. It focuses on how different the parts of the phenomenon under the study interrelate as a whole object. In other words, it describes how troubleshooting is being enacted by the lecturers, laboratory technologists and students in an electronics engineering programme.

3.1.2 (b)The external horizon

The external horizon of the way of experiencing a specific phenomenon is concerned with discerning the phenomenon (Marton & Booth, 1997; Khan, 2014). This is "what informs" the act, the intention for the action that is carried out in a particular way. It expresses the why of the internal horizon. In this study, it answers research question three on what informs the how, and also informs the intention for the how action, in the participants' views. The external horizon of the structural aspect of experience has an indication of similarity to the referential aspect, but differs in analytical meaning and application (Marton & Booth, 1997). The two do not connote the same meaning. The external horizon of the structural aspect is applied at the level of inference to the research question "how", showing the intention for the how of the action, it focuses on the "what informs" the practice of a phenomenon. The inferential aspect reflects the general understanding of the particular phenomenon under study. This is how the different parts of the phenomenon are brought together, experienced and enacted. In this study, this aspect addresses what influences how an electronics engineering programme is being enacted, the intentions underlying the enactment of the electronics engineering programme in a particular way in engineering education. This becomes a derivative of research question two that deals with how an electronics engineering programme is being enacted. Three queries are to be answered using the phenomenographic analytical approach in the present study. The three queries are the "what", the "how" and the "what informs" the place of troubleshooting in an electronics engineering programme.

3.2 Space and place as theoretical frameworks – a historical review

According to Agnew (2011), the idea of putting space and place theoretically into a working framework requires a continuum running from the nomothetic (generalised) location of space at one end to the idiographic (particularistic) place at the other end, especially when analysing the geographic meanings of space and place. There are four prevailing theoretical perspectives of space and place that have been developed from the seventeenth century to the present twenty-first century. The following theoretical perspectives have been highlighted:

a) The humanistic or agency-based theory
b) The feminist theory
c) The performative theory
d) The neo-Marxist theory of space and place (Agnew, 2011, pp. 17-18).

The above three perspectives are only discussed in brief; however, a lengthy section is dedicated to Lefebvre's theory of space because his theory informs this study.

The humanistic or agency-based theory

This theoretical perspective was pioneered by Tuan, who drew his ideology from geographic experiences (Tuan, 1979). According to Tuan, the humanistic theory of space and place focuses on relating location to place through the experience of human beings as agents. In this framework, places are seen as woven together through space by movement and the network ties that produce places as "changing constellations" of "human commitment", "capacities and strategies" (ibid. 394, 395). Places are seen as parts of spaces. The space provides the resources and the frames of reference in which places are made (ibid. p. 421).

The feminist theory of space and place (Massey, 2013)

Doreen Massey was one of the pioneers that wrote on space and place from the feminist theoretical perspective. She facilitated the views of dominance between men and women, the identities of subjects and places through interrelations that open the opportunity for the possibilities of future changes (Massey, 1994). Agnew (2011) argues that Massey's perspective of place includes location and place but without a focus on individual human agency that brings these together and without the division between representation and practice in the Lefebvre's neo-Marxist perspective. In feminist claims, place is regarded as constituted out of space-spanning relationship, place-specific forms and sense of place associated with the relative well-being, disruption, and experience of living somewhere (ibid. p. 20).

The performative theory of space and place (Thrift, 1999)

The performative theory of space and place, as argued by Thrift (1999), claims that place is associational; it weaves together all manner of spaces and time. According to Agnew (2011), the performative theory found its point of departure from Lefebvre's neo-Marxist theory on the division between representation and practice that is commonly used in relating space and place. Thrift (1999) emphasises the materiality of places as "open spaces" that practises and that take shape only in their passing.

The neo-Marxist theory of space and place (Lefebvre, 1991)

The neo-Marxist perspective, which is the preferred lens in this study, is best represented and described in the writings of Henri Lefebvre (Lefebvre, 1974, 1984, 1991 & 2012). His work exposes what appears to be obscure in the production process. His framework focused on the social production of spaces within which social life and social interaction takes place (Elden, 2004; Lefebvre, 2009). His background and theoretical perspectives will be traced in the following part of this chapter.

3.3 Introduction to Lefebvre's theory of space

Lefebvre (1901-1991) was a French neo-Marxist philosopher best known for pioneering the critique of everyday life, for introducing the concepts of the right to the city and the production of social space, and for his work on dialectics and alienation (https://en.wikipedia.org/wiki/Henri_Lefebvre). Lefebvre built upon a Marxist idea of production, to clarify the so-called dynamic relationships of capitalist commoditisation and acknowledged that space itself is an active moment that needs to be actively produced and not just left to its own devices

In an attempt to discuss the theoretical concept about space, which underpins this study, it is pertinent to first understand the origin of the concept of space as presented by Lefebvre in his writing on the production of space (Lefebvre and Nicholson-Smith, 2012). Lefebvre and Nicholson-Smith (2012, p. 11) analyse the concept of space from the seventeenth century through to the twentieth century. In the opening passages of the Lefebvre's production of space, (Lefebvre & Nicholson-Smith, 2012, pp. 1-7), discusses the origin of the concept of space. He introduced the concept of space by connecting three theoretical fields namely: (i) the traditional philosophy of space (Aristotelian), to (ii) the science of space (mathematical) and (iii) the modern field of epistemology (mental and ideological space). Thereafter, Lefebvre put these pieces together, backed up with his neo-Marxist philosophical idea to come up with a "unitary theory", with the main aim of constructing a theoretical unity from the fields (ibid. p. 11). It is important to note that Lefebvre did not pursue a full discourse on space, rather on the production of space (ibid. p. 16). Lefebvre's discourse and theoretical ideology is captured as below:

> *The project I am outlining, however, does not aim to produce a (or the) discourse on space, but rather to expose the actual production of space by bringing the various kinds of space and the modalities of their genesis together within a single theory*
> (Lefebvre & Nicholson-Smith, 2012, p. 16).

According to Lefebvre, there is need to bring previous ideas on space together as one theoretical construct. Lefebvre's work is influenced by his neo-Marxist ideology of production. Discussed below is Lefebvre's articulation of the link between the three fields before arriving at a unitary theory.

3.3.1 The traditional philosophy of space

Lefebvre began his argument for the production of space from the Aristotelians tradition of space and time (Lefebvre & Nicholson-Smith, 2012, p. 1). Accordingly, Lefebvre argued that the Aristotelians held the view that space and time were among the categories that facilitated the naming and classing of the evidence of the senses (ibid. 1). In his argument, the Aristotelians conceived space as one of the mental categories by which the various objects of the world receives their naming and classifications (ibid. 1). However, the Aristotelians' concept of categories seems unclear until the development of Cartesian logic, which advanced space concept to "the realm of the absolute", "as an object opposed to the subject" (ibid. p. 1). Subsequently, Descartes, a contemporary of Newton, Spinoza and Leibniz, challenged and ended the Aristotelian tradition of space and time. As Lefebvre asserted, space was conceived as absolute and place as concrete and real (Ibid. p. 1). Alongside with Descartes in the course of emancipating space from the old tradition of the Aristotelians were the Newtonians and Spinoza, who took the view of the absolute realm of space (Ibid. 2).

Agnew (2011) in his description of space and place reported that the Newtonians viewed space as active, because it is made up of places where things are located within a force field at any particular moment. However, Leibniz was observed to have a different perspective of viewing space as relational rather as being absolute or a separate distinct object (ibid. p. 8). Leibniz conceived space as an entity that is dependent on the process and substances that make it up (ibid. p. 9). Kant attempted to revive and revise the old notion of space as a realm of consciousness, of subject rather than the object of space (Lefebvre & Nicholson-Smith, 2012). This scenario led to a prolonged debate, which led to the shift from philosophy to the science of space. Before the advent of the scientists (particularly, mathematicians), the philosophers conceived space first as subject (the Aristotelian categories of naming and classing), secondly as absolute space (Descartes and his contemporaries) and lastly as an attempted return to the subject (Kent), before the mathematicians took over the scene.

3.3.2 Science of space by the mathematicians

According to Lefebvre, the debate on whether space should be considered as subject or object continued to raise pertinent issues such as the questions of symmetry versus asymmetry, and of symmetrical objects (Lefebvre & Nicholson-Smith, 2012, p. 2). The modern mathematicians however waded in, "appropriated space and time and made them part of their domain" by inventing and re-inventing space (ibid. p, 2). The mathematicians invented the non-Euclidean spaces, curved spaces, infinity spaces, abstract spaces and so on. Lefebvre argued further, the attempt created a deep rift between physical or social reality and mathematicians subsequently abandoned the challenge to the philosophers (ibid. p. 2). Thus philosophers seized the opportunity to introduce space as a "mental thing".

3.3.3 The modern field of epistemology

The last stage on the origin of space as expressed by Lefebvre emanated from the epistemological school of thought. As Lefebvre and Nicholson-Smith (2012) puts it; "from a philosophy of space revised and corrected by mathematics – the modern field of inquiry known as epistemology has inherited and adopted the notion that the status of space is that of a "mental thing" or "mental space". According to Lefebvre & Nicholson-Smith (2012, p. 6), the epistemological ideology of mental space became the net result of a deformed or diverted theoretical practice or forced dominant practice. Lefebvre believed that the dominant ideas that are compelled by the dominant class of the society originated from the idea of mental space. Mental space is the space of the philosophers and epistemologists, which then becomes the pivot and locus of a "theoretical practice", which is separated from the social practice and which sets itself up as the axis, pivot or central reference point of knowledge (Lefebvre & Nicholson-Smith, 2012, p. 6).

Based on the foundation so far laid on the notion of space, which cannot be exhaustive in this context, I turn to address the Lefebvre's perspectives of space. Lefebvre thought it necessary and significant to bring up a "unitary theory" that aim at constructing a theoretical unity between various fields, which are involved on the context of space. The fields of concern to Lefebvre are; the physical (the nature and cosmos), the mental (including the logical and the formal abstractions) and the social (Lefebvre & Nicholson-Smith, 2012). In other words, Lefebvre focused on the logico-epistemological space, which he referred to as the space of the social practice, the space occupied by the sensory phenomena including products of the imagination such as "projects and projections", "symbols and utopias" (pp 12). In order to portray the ontological unity of space and place in social production, Lefebvre denotes three instances referred to as triads in the production of space which serves as the conceptual structure of space and place (Weaver, 2013, p. 32). Each instance of the production process therefore corresponds to one of the three conceptual categories. These are the three-fold spatial dialectics of Lefebvre.

3.4 Lefebvre’s spatial theory

In his discourse, Lefebvre portrayed the space produced by economic transactions and state policies which had colonised everyday life by means of bureaucratisation and commodification as “abstract space” through the discourses of planning and surveillance (Lefebvre, 2009; Agnew, 2011). Abstract space is the space of dominance, the space of power, manipulated by all kinds of authorities, which does not take the space of the users into consideration (Lefebvre & Nicholson-Smith, 2012). According to Lefebvre and Nicholson-Smith (2012), the Soviet urban planners of Lefebvre’s days were criticised on the basis of failing to produce socialist space, having just reproducing the modern society model of urban design by the actions of those in the abstract space. Lefebvre contended for a movement against this form of colonisation of what he referred to as concrete space to the reforming and reviving of the spaces of everyday life (ibid. pp. 88-89). This he, like Marx, felt could be accomplished by insurgent “counter-discourses” or a rising in opposition through philosophical discourses that build on the memories of an older authentic existence and projected new practices in concrete space. Lefebvre’s description of “concrete space” signifies a place which is a bottom-up and autonomous reaction to the oppressions of the agents of capital and state whose dominance has produced the abstract space (Lefebvre and Nicholson-Smith, 2012). Concrete space is the space of everyday life in the social space, the directly lived space associated with symbols; it is the space of the inhabitants and users, the underground side of social life.

The basic framework of Lefebvre’s theory of space, which is commonly called Lefebvre’s triads, identifies the three categories of representations as the spatial practice, representations of space and spaces of representation. In order to properly capture the theoretical framework of Lefebvre’s production of space that will be applied in this study, Elden’s (2002) structural and schematic diagram will be adapted.

Spatial practice	Perceived	Physical
Representation of space	Conceived	Mental
Spaces of representation	Lived	Social

Table 2: Structural framework of Henri Lefebvre's triads (Adapted from Elden, 2002, p. 30)

Table 2 clearly shows the relationship between the conceptual triads of Lefebvre as presented by Elden (2002). Lefebvre discussed the conceptual triad that emerged, which comprises three categories of spaces (Lefebvre & Nicholson-Smith, 2012, pp. 33, 38-39). The first is the *Perceived Space*, also known as the spatial practice, the physical space, the common sense belief, personal space, passively experienced space, characterised by spatial hierarchies, forbidden spaces, territorial imperatives, ventilations of disciplinary knowledge, and how thought becomes real action. Secondly, there is the *Conceived Space*, also referred to as the representations of space, the mental space, and the space of imagination. It is the distance or desired space, access or denial space, places of popular spectacle, spaces of fear and the space of abstractness. It could also be referred to as the space produced by economic transactions and state policies, constructed by professionals. Lastly, there is the *Lived Space*, also called the spaces of representation, the lived and the endured space. It is the *experienced concrete space*, the directly lived space associated with symbols. The lived space is well-known as the space of inhabitants and users, the underground side of social life and the combination of the conceived, the perceived, physical and mental life. This is the space influenced by wider, social, economic and political processes. Lefebvre's conceptual triad is widely described in literature (Agnew, 2011; Delaney, 2008; Elden, 2004; Massey, 1994), Merrifield, 2013; Weinert, 2015). Lefebvre stressed that the three moments in the conceptual framework of production of space are relational and should be treated as internally interrelated in the analytical sense of it (Lefebvre & Nicholson-Smith, 2012, p. 155).

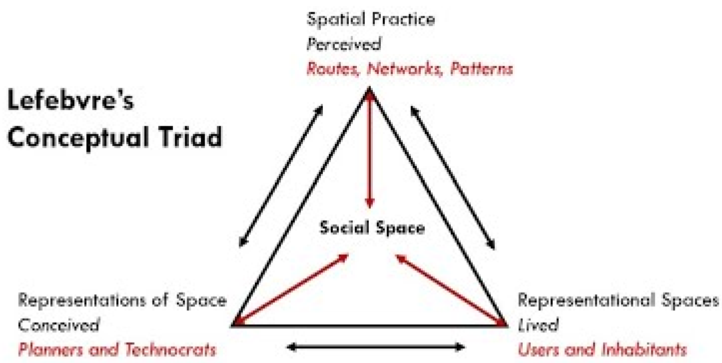


Figure 4 Lefebvre's conceptual triad

Lefebvre (1991) never uses the term 'place' in his representations of the conceptual framework of the production of space. His description however shows that the "concrete space" signifies a place which is a bottom-up and autonomous reaction to the oppressions of the agents of capital and state whose dominance has produced the abstract space. He developed a unitary idea of space which is a product of three-dimensional social space which is dialectically related and became the popularly known trialectics of spatial theory (ibid. p. 40). This comprises the three dimensions reflected in Fig. 3:1. These are: firstly, spatial practice, which is known as the *perceived space*; followed by the representations of space which is captured as the *conceived space*, the codified space produced by the technocrats, the engineers, the forces of production, the policy formation space, and could be called the mental, imaginative and theoretical space; and the last, representational spaces, these are the directly *lived space* (ibid. pp. 38-39).

Lefebvre portrayed the conceived space as that of the capitalist which seeks to suggest oppression, prohibiting others, denying access to products of production and economic growth through various policies and popular spectacles (Lefebvre, 1991, p. 73). He further criticized the actions of the ruling class, the bourgeoisie, which suppress the individual's economic growth. He argued that the problem that resulted in such actions is that the conceived spaces in most cases do not match the perceived and lived spaces of everyday life. He equally acknowledged that space itself is an active moment that needs to be actively produced and not just left to its own devices. In Lefebvre and Nicholson-Smith's (2012, pp. 47-50) account, he anticipated a space of production that demystifies the dynamic relationships of capitalist commoditisation, and that compelled him to advocate for an insurgence into the activities of the ruling class. Lefebvre contested the implication of power in the reproduction, construction and contestation of places and their end result, which is a capitalist society. In his view, this perception is limiting and suppressive. The conceived space of the capitalist has beclouded and colonised everyday lives and lived experiences (places). He was obsessed that the process is often reproduced, and the product of such is dominance and power control. The overpowering influence of the abstract space was described in Lefebvre's words as stated thus:

> *"Perhaps it could be true that the place of social space as a whole has been usurped by a part of that space endowed with an illusory special status – namely, the part which is concerned with writing and imagery, underpinned by the written text, and broadcast by the media; a part, in short, that amounts to abstraction wielding awesome reductionistic force vis-à-vis lived experience"* (Lefebvre, 1991, p 52).

Lefebvre attempted to demystify the notion of usurping the place of the social space by the abstract space. He argued for a contradiction of abstract space, the reproduction of social relations of production, which are meant to obey two tendencies, namely, the dissolution of old relations on the one hand and the generation of new relations on the other (Lefebvre, 1991). His argument was anchored on the reclaiming of the spaces for everyday life and this could only be achieved by a counter-discourses insurgency based on the experiences of those in the spaces of representation, those in the lived space. A new kind of space named 'differential space' was solicited, a space that will restore unity to what abstract space breaks up in the functions, elements and moments of social practice (ibid. p. 52). He also advocated for a spatial turn in policy, education and economic institutions.

3.5 Critique and extension of Lefebvre's theory - Merrifield (1993) and Soja (1989)

Merrifield (1993) illustrates the relationships between space and place as constituted in Lefebvre's words as dialectical. Space is compared to the fluid of material flow in space, while place constitute a form of object in space that could obstruct the fluid flow. In Lefebvre's term, the conceived represents the space, while the lived represents the place. Merrifield (2013, pp. 521, 525) criticised Lefebvre's use of the phrase 'dialectical relation of space and place in production of space'. He claimed that it does not clarify the relationship between the abstract space and concrete place, rather it obscured it. However, Lefebvre's work has focused on contending how uneven economic development is jointly produced by dominant practices and discourses but can only be challenged by and on behalf of people in places attempting to recapture concrete space (place) from the abstract space of modern capitalism (Lefebvre, 1991, p. 122).

Lefebvre's argument was further extended by Soja (1989) as the theory of the trialectics of space. He modified and redefined Lefebvre's theory of production of space. Soja's theory is tripartite, with three tiers of methodology called first space, second space and third space (Soja, 1989, p. 75). Soja's first space is characterised as an objective component, which centres on the physical space, and aims at a formal science of space to favour materialism; this aligns with the perceived space in Lefebvre and Nicholson-Smith's (2012) theory. The second space in Soja's theory is a cognitive space, one's imagination of the physical space, it exists as a space that is constructed in the mind; it aligns with Lefebvre and Nicholson-Smith's (2012) conceived space. The third space in Soja's theory is the space of the lived experience, which actually combines both the physical place and the mental space; it is the potentiality that comes from first and second spaces; also Lefebvre and Nicholson-Smith's (2012) lived space. Soja's theory suggests how uneven economic development is jointly produced by dominant practices and discourses. Such process can only be challenged by and on behalf of people in places attempting to recapture concrete space (place) from the abstract space of modern capitalism (Soja, 1989). Soja's theory suggests that everything in the society is spatially constituted, and that all spheres, ideologies, relations and realms are spatial (Soja, 2003, p. 116). Soja's and Lefebvre's compared model is as shown in Figure 5.

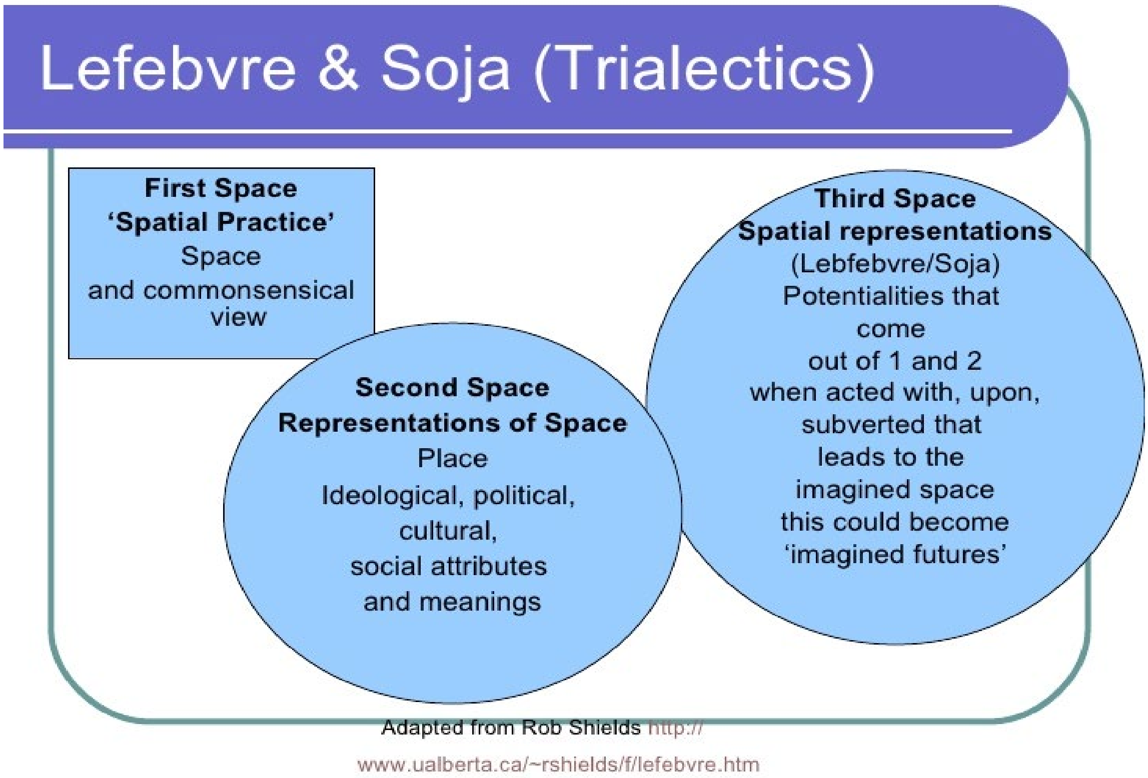


Figure 5 Lefebvre's and Soja's conceptual trialectics of space (Shields http://www.ualberta.ca/~rshields/f/lefebvre.htm)

Soja's first space, second space and third space, are three separate forms of spaces showing that the triad constitutes three dialectical processes of production rather than three separate interconnected spaces, rendering Soja's theory fundamentally different to the Lefebvre's spatial triad. Soja's theory is characterized by the same three spaces as Lefebvre but differs conceptually.

3.5 Conclusion

This chapter presented the phenomenographic analytical tool used in this study. The basic concept of phenomenographic analysis and how it is positioned in the analysis of data that is generated from the study was expounded. The analytical tool addressed the three research questions that were proposed for study using the three aspects derived from the tool, namely, the referential aspect, the internal horizon – structural aspect and the external horizon – structural aspect. The referential aspect answers the "what" question which is applicable to research question one, the internal horizon – structural aspect answers the "how" question which addresses research question two, and the external horizon – structural aspect answers the question "what informs" which provides answer to the third research question of the study. The analytical tool equally provides three queries to interrogate the narratives of the respondents, namely by the use of "what", "how" and "why" to find out the relevant categories of description and outcome spaces in the study.

Lefebvre's theory of space was explored and discussed as it applies to this study. The theory deals with three spaces that are supposedly required to operate in unity. These spaces are the conceived, the perceived and the lived. Lefebvre observed that the spaces were not in unity in the social space, which he contends theoretically, and suggests the triad should be used to theorise similar relationships in other spaces, including educational spaces. Lefebvre's theory presented in this chapter is applied to locating the place of troubleshooting in electronics engineering education programmes. Three spaces relating to Lefebvre's spaces were identified, namely, the conceived space of CHE and ECSA in South Africa, the perceived space of electronics engineering institutional curriculum, lecturers and laboratory technicians, and the lived space of fourth year electronics engineering students. Thus, Lefebvre's theory of space will be used to theorise the findings from the analysis of results in the present study.

This chapter presented the analytical tool and the theoretical framework for the study. The next chapter will provide the methodology that will be used to carry out the study, the research design and the procedure for data analysis.

CHAPTER 4

THE METHODOLOGY USED IN THE STUDY

4.0 Introduction

As highlighted in the earlier chapters, this is an explorative qualitative case study which sought to understand the ***place*** of troubleshooting in undergraduate electronics engineering programme at a university in South Africa. Exploratory qualitative case studies are conducted when there is need for an in-depth, detailed and complex understanding of a certain phenomenon (Creswell, 2013). Such detail can only be rooted in the available data collected from participants by talking directly to them, going to their homes or institutions, and allowing them to narrate their experiences or stories, irrespective of what we expect to find or what we have read in the literature (ibid.). Furthermore, Cohen, Manion and Morrison (2011) argue that exploratory qualitative case studies also help to empower individuals to share their stories, hear their voices and minimize the power relationships that often exist between the researcher and the participants. Since the "concept" of troubleshooting and its "place" within university electronics programmes isn't that well established and entrenched in the literature, an exploratory qualitative research design was deemed appropriate. It is hoped that, through this critical exploration of "what place troubleshooting occupies", "how the electronics engineering programme was enacted" and "what informs this enactment", this case study will offer an effective way of laying the groundwork that would lead to future studies. The two frameworks that guided this study are phenomenography and Lefebvre's theory of space. Whilst phenomenography guided and informed both the methodology and analysis, Lefebvre's theory of space guided the theoretical aspects of the study. Their methodological basis and implications are discussed below.

The chapter is thus divided into two main sections. Section 4.1 revisits the analytical and theoretical framing of the study, section 4.2 describes the sampling techniques, and section 4.3 unpacks the data collection procedure while section 4.4 expounds the data analysis processes. The remaining sections are section 4.5 – ethical consideration, section 4.6 – validity and reliability, section 4.7 – rigour and finally section 4.8 – the conclusion for the chapter.

4.1 Revisiting the analytical and theoretical framing of the study: Phenomenography and the theory of space

Phenomenography is a field of inquiry that provides qualitative researchers with experiential descriptions of the phenomenon under study (Marton, 1986). The aim of developing this approach in research is to describe, analyse and understand experiences in qualitatively different ways in an empirical manner (Bowden, 2000; Marton, 1986). In this regard, it is the empirical study of the different ways in which people think of the world. In other words, its aim is to discover the qualitatively different ways in which people experience, conceptualize, realize and understand various aspects of phenomena in the world around them (Marton et al., 1992). Phenomenography seeks to describe the significant, or critical, features of the different ways individuals experience a phenomenon. This is the second-order view of the development of knowledge where a researcher is not making statements about a phenomenon directly, but rather about individuals' ideas of that phenomenon. In other words, our interest is not to describe things as they are, instead, things are characterised the way they appear to people (Marton, 1986, p. 33). The researcher's primary concern is how the phenomena is being conceived the way it is, how it is conceptualized by the participants. The researcher accepts the data in the way it is reported and experienced. In this study, the data is related to the pedagogical aspects of an electronics engineering education programme. The lecturers and technicians characterized troubleshooting differently the way it appears to them. For instance, some lecturers conceptualize troubleshooting as something theoretical that could be tested through written examinations while others see it as embedded in design testing and evaluation. Furthermore, some students conceptualize it as embedded learning in debugging and software programming.

In applying Lefebvre's spatial theory in the pursuit of the production of space, the framework shows, as discussed in Chapter 3 (Section 3.29), that there are three basic categories; the *spatial practice*, *the representation of space* and *the representational space*. There is a relationship between the categories and connections between them. In order to understand the application of Lefebvre's theory to the context of the present study, there is a need to dissect the relationships in the elements of production as prescribed by Lefebvre. In Lefebvre's theory, spatialisation of dialectical (internal) social relationships is emphasised. This means that the elements of production do not exist or operate in isolation to contribute to the process of production but are internally related in a dialectical manner. The role of each category to each other attests to the production of social space that exists. Specifically, the conceived and lived space produce the perceived space, the perceived and lived space produce the conceived, whereas the conceived and the perceived space produced the lived, experienced space. The combinations of the three moments of relationships produce and reproduce the social space in the society. For a change in social space to occur, there must be some kind of disruption of the spatial practices which will affect the initial traditional approach. This disruption is the insurgence "counter-discourses" which Lefebvre advocated (Lefebvre, 1991; Agnew, 2011). To engage effectively in the discourse on the object of the study, the phenomenographic analytical framework provides the strong methodological base for relevant data. This is reflected in the variation of ways of conceptualizing the phenomenon of study, using the data generated. Lefebvre's theory is used to theorise the results from the phenomenographic analysis data on the phenomenon of troubleshooting in electronics engineering education programme.

4.2 Unpacking the methodology used in the study

As argued by Creswell (2014), the research methodology is informed by the research design of the study. According to Denzin and Lincoln (2011) and Creswell (2014), the type of inquiry selected in a study provides the specific direction for procedures and strategies to be used. Figure 1 of chapter one (section 1.4) presented the structure of inquiry adopted in this study in stages. These stages illustrate how the study was conducted from the data sources to the final stage of application of theory as a lens for the phenomenon being studied. The structure provides a link between the analytical and theoretical framework of the study. As mentioned in Chapter 1, data were built from two main sources, namely documents and open-ended interviews from participants. The study was conducted in three major phases as described below.

Phase 1

The first phase involved visiting the site of data collection, a university in KwaZulu-Natal, South Africa. The engineering section of the campus was visited to collect data from the electronics engineering department in order to answer the first research question. This involved consulting with the documents (programme handbook and laboratory manuals) for information on the curriculum for electronics engineering undergraduate students. CHE and ECSA documents were also consulted. This enabled the researcher to answer part of research question one.

Phase 2

The second phase involved conducting individual interviews for the electronics engineering lecturers, laboratory technicians and the fourth-year undergraduate electronics engineering students to answer the research questions one and two of the study.

Phase 3

The third phase involved conducting focus group interviews with the three categories of participants to gain insight into the third aspect of the research question. It included the students, the electronics engineering lecturers and laboratory technicians. This phase answered the third research question on what informs how the electronics engineering programme was enacted. The results from the three phases were then subjected to analysis using the documents and phenomenographic analytical approaches. The outcome of these analyses culminated in the final theorisation of the study, using Lefebvre's theory of space.

4.3 The sampling method

According to Cohen, Manion and Morrison (2011), it is imperative to clearly understand the concept of sampling before engaging in conducting qualitative research of any type, especially before the data collection process. In qualitative research, the emphasis is placed on the uniqueness, the exclusive distinctiveness of the phenomenon, individuals or group in question in the study. Therefore, as the individual or group represent themselves and nothing or nobody else, qualitative research seeks to explore a particular group under study and not to generalize. Creswell (2013) argues that the process of sampling involves making decisions about which people, settings, or events to include in the study. Since everyone and every event cannot be studied due to research timeframes, researchers need to sample their participants to represent an individual or group in relation to a certain phenomenon. Fraenkel, Wallen and Hyun (2012) emphasize the role of sampling, arguing that one of the most important steps in the research process is the selection of individuals who will participate either by being observed or by being questioned. Researchers within the interpretive paradigm within which this study is situated are concerned with detailed and in-depth description and analysis rather than with statistical accuracy (Creswell, 2013). These characteristics support the need for the purposive type of sampling selected for this study.

Purposive sampling

Purposive sampling is a feature of qualitative selectivity research method. Cohen, Manion and Morrison (2011) describes it as a non-probability sampling method which derives from the researcher targeting a particular group, in the full knowledge that it does not represent the wider population, it simply represents itself. Like other types of non-probability samples, purposive sampling seeks only to represent itself in a similar population rather than attempting to represent the whole, undifferentiated population (Cohen, Manion & Morrison, 2011). This selection method fits with this study due to its characteristics of providing greater in-depth understanding of the study from the few samples that are purposively selected from the electronics engineering programme in a university engineering education programmes. The target population simply represents an electronics engineering category that is involved with teaching and learning in the electronics engineering programme.

Another characteristic of purposive sampling is the concern to select and use those who have in-depth knowledge about a particular phenomenon or issue and are in a position to give relevant in-depth information (Cohen, Manion & Morrison, 2011). It is believed that the selected participants of this study are (i) those who by virtue of their professional role in the university engineering education are significantly placed, (ii) those who have the control of the engineering education programme (iii) those who possess some professional expertise and experience, and (iv) those who experience the phenomenon directly; these are inclusive in the purposive and careful selection made. In order to achieve representativeness and comparability, Teddlie and Yu (2007) as well as Teddlie and Tashakkori (2009, p. 174) provide several kinds of purposive sampling techniques among which are typical case sampling, extreme or deviant case sampling, intensity sampling, maximum variation sampling, homogeneous sampling and reputational sampling techniques. Two of these purposive kind of sampling techniques were considered and employed. Firstly, the purposive typical case sampling technique, which allows the sample to be constituted with the most typical cases of the population that are concerned with the phenomenon of study. This was combined with a maximum variation purposive sampling technique in which the sample chosen exhibited a wide range of characteristics with regard to the phenomenon of study. The participants fitting into these two types for the case of troubleshooting in electronics engineering education programme were purposively selected for this study as follows:

a) six (6) fourth-year undergraduate electronics engineering students;
b) three (3) electronics engineering lecturers;
c) two (2) laboratory technicians and

d) one (1) ECSA member.

The six fourth-year students were from the electrical, electronics and computer engineering programme. They study electronics and computer engineering courses from their first year to their fourth year and have the potential to experience troubleshooting to a large extent more than their counterparts in lower levels of studies. The lecturers, laboratory technicians and ECSA member were staff from electronics and computer engineering programme and have acquired years of experience on their job. Table 3 provides the information containing the characteristics of the sampled population for the study.

Participant type	Sample size	Working experience with industry	Working experience with university	Courses offered/taught
Students	6	2 - with previous industry experience 4 – without previous industry experience	Nil	Electronics and Computer engineering programme modules
Lecturers	3	2 – with industry experience 1 – without industry experience	Between 12 – 23 years of experience	Analogue electronics, industrial projects, nuclear semiconductor, semiconductor physics, individual and group design project supervision, etc.
Technicians	2	1 – with industry experience 1 – without industry experience	Between 20 – 28 years of experience	Conduct laboratory practical for students
ECSA member	1	With industry experience	6 years' experience	Applied management, embedded system, circuit theory, Digital system, Computer Architecture

Table 3: Demographics of participants

Table 3 above provides the demographics of participants purposively selected for the study. All the selected participants are typical of engineering education programmes and possess a wide range of engineering education behaviours. The four categories of participants are amongst the most typical set of people concerned with troubleshooting and electronics engineering; they also exhibited variations in that they had different characteristics – lecturers, technicians, students and ECSA member. The fourth-year students were the most appropriate for this study because at that level the electronics engineering students have got experience from the first year all through to the fourth year; they also get involved in personal practical projects which they design and implement on their own. At this level of their study, all their previous learning experiences from first year to fourth year are consolidated.

4.4 Data collection method

As an exploratory qualitative case study, the instruments that were selected were from those suggested by Creswell (2013) and Cohen, Manion & Morrison (2011): documents analysis and interviews. This study engaged these instruments for the purpose of data collection in order to answer all the research questions proposed.

4.4.1 Documents

To generate data on the place of troubleshooting in electronics engineering programmes, particular attention was given to what is foregrounded in the White Paper documents from the Council on Higher Education (CHE), Engineering Council of South Africa (ECSA) and the electronics engineering handbook from the university. The electronic version of the South African Qualification Standard for the Bachelor of Science in Engineering, from the Council on Higher Education (CHE, 2015) and the accreditation requirements from the Engineering Council of South Africa (ECSA, 2017) and current electronics engineering programme handbook from a conventional university were retrieved and consulted as document sources of data for the study.

4.4.2 Open ended interviews

Interview is the second instrument used for data generation in this study. According to Cohen, Manion and Morrison (2011), interview is a flexible tool for data collection, enabling multi-sensory channels to be used; verbal, non-verbal, spoken and heard. It enables the participants, be they the interviewer or interviewees, to discuss their interpretations of the world in which they live and to express how they regard situations from their own perspectives. In such a situation, collection of data about a phenomenon is not just simply an academic exercise ~~the concern~~, rather its human embedded quality is inescapable and it is part of life itself (ibid. p. 409). The interview method comprises different types, namely, the closed-ended interview, standardised open-ended interview, informal conversation interview and informal guide approach (Cohen, Manion & Morrison, 2011). The open-ended unstructured interview was selected for the purpose of this study because of its strength in the aspect of allowing the same questions to be answered by the respondents, thus increasing comparability of responses from each of the respondents. An unstructured open-ended approach also facilitates organization and analysis of the data. An interview protocol was used to guide the interview process and recording of relevant notes. This was done by making handwritten notes on the protocol where necessary. The interview process was audio recorded and transcribed after collection.

4.4.3 The phenomenographic interview design

One aspect of planning a phenomenographic research that distinguishes it from other qualitative approaches is in the methodology that underpins its data collection approach (Collier-Reed & Ingerman, 2013). Data collection in phenomenographic interview represents the relationship between the participant and the phenomenon in the world as described by the participant (ibid.). Therefore, the uniqueness of the interview approach is found in that it facilitates the participant's reflection on their relationship with the phenomenon. Such reflection that will elicit relevant responses does not just manifest naturally, an appropriate method of data collection is required to enable it to happen. The interview questions should be so chosen and drafted to encourage the participant to express their qualitative understanding of the phenomenon under investigation. Bowden (2000) advised that the researcher may ask the participant to clarify what they have said, and ask them to explain their meaning further. It allows the participant to relate with the phenomenon freely as they express their conceptions about the world. The participant and the researcher also establish a shared definition of the phenomenon (ibid, p. 58).

On the basis of this study, the semi-structured interview questions were drafted in line with the research questions of the study. The three research questions align with the three aspects of phenomenographic research structure, namely,

i. The "What" question – referential aspect
ii. The "How" question – structural aspect (internal horizon)
iii. The "Why" question – structural aspect (external horizon)

The interview questions were asked around these three questions on the phenomenon of troubleshooting in the electronics engineering programme. The questions asked from the participants were all open-ended. The first set of questions elicited different ways in which the participants perceive the phenomenon and the meaning they focus on when they are confronted with the phenomenon of troubleshooting. The second set of questions elicited information about the approach, how troubleshooting is being approached; in other words, what strategies are employed based on their experience and perceptions, or how the programme is enacted. The last set of questions elicited information on the intentions behind the enactment descrined in the second section. The interview questions did not seek 'correct' answers from the participants, but their own conceptualisation of the phenomenon at the time of the interview.

4.4.4 Focus group interviews

Rather than relying on individual interview information, a focus group elicits interactive responses between and among the participants (Cohen, Manion & Morrison, 2011). To elicit a collective view of participants' characteristics present in this study, a section of the data collection process was devoted to a focus group interview. This allowed the participants to interact with each other rather than with the researcher only, such that their views emerged, rather than the view of the researcher who dominated the interview process. The first two research questions in this study were answered through individual interviews, while the last research question was answered in a focused group interview session. Focus groups were planned for three groups of participants – the electronics engineering lecturers, the laboratory technicians and the fourth-year electronics engineering students. Due to the limitations this study encountered in accessing the participants, the only focus group interview held was with the fourth-year electronics engineering students. The focus group for other participants could not take place owing to their busy schedules. The other participants were instead met individually to address the interview questions under the last research question. The summary of data collection method is presented in Table 4.

Phase/Parts	Research Questions	Data Source	Instruments
	PHASE 1		
Part 1 (a)	**RQ 1**: Is troubleshooting accommodated in the electronics engineering programme? (i) If so, what was foregrounded by:	All data sources	Documents/Interviews
Part 1	(a) CHE, ECSA and Electronics Handbook/documents?	CHE (2015), ECSA (2017) and Electronics department	Document analysis
Part2	(b) the fourth-year students?	Electronics engineering students	Individual Interviews
Part 3	(b) Electronics lecturers and laboratory technicians?	Electronics engineering lecturers and laboratory instructors	Individual Interviews
Part 4	(c) Engineering Council of South Africa (ECSA)	ECSA members	Individual Interviews
Part 1 (b)	(ii) If not, what was foregrounded by: the above list in 1(a)?	Electronics engineering lecturers and laboratory instructors	Interviews
	PHASE 2		

	RQ 2: How is the electronics engineering programme enacted by:		
Part 1	(i) the fourth-year students	Electronics engineering students	Interview
Part 2	(ii) the lecturers?	Lecturers	Interview
Part 3	(iii) laboratory technicians?	Laboratory Technicians	Interview
		PHASE 3	
	RQ 3: What informs:		
Part 1	(i) how EEP has been enacted by the students?	Electronics engineering students	Focus group interview
Part 2	(ii) how EEP has been enacted by the lecturers	Lecturers	Focus group interview
Part 3	(iii) how EEP has been enacted by technicians?	Laboratory technicians	Focus group interview

Table 4: Summary of data collection methods

4.5 Data analysis

In order to systematically analyse the results from data collected, I utilized two approaches: (a) documentary analysis, particularly, Jansen and Reddy's (1994) document analytical tool was used followed by (b) the phenomenographic approach of data interpretation and analysis. Jansen and Reddy's policy document analytical tool involves unpacking the policy into its component parts. It helps to discover the purpose of the document and identify problem areas that need to be fixed. Policy analysis is also required for the purposes of identifying gaps and silences. The phenomenographic approach of data interpretation and analysis examined the depth of understanding of electronics engineering programme participants about the place of troubleshooting in the programme, how it is being perceived by academia, conceived by policymakers and lived in the everyday practice of electronics engineering students.

4.5.1 The data analysis process

Data analysis aims to determine the representation of variations in the participants' view about the phenomenon under study. According to Cohen, Manion and Morrison (2011), qualitative data analysis involves organizing, accounting for and explaining the data. In further description, qualitative data analysis involves making sense of data in terms of the participants' definitions of the situation, noting the patterns, the themes, regularities and categories. In order to seek the variations in meaning within participants' responses, rigorous analysis and an iterative approach was conducted. This involved the researcher and the promoter (supervisor) of the study. The data analysis was sub-divided into two sections.

4.5.2 Documents analysis

The first section of data analysis that has to do with document analysis was conducted through the use of Jansen and Reddy's (1994) ideas on policy and document analysis. The document analysis process was guided by suggestion and ideas from Jansen and Reddy (1994) on policy and document analysis. Jansen and Reddy's (1994) document analytical tool suggests four factors to be considered in analysing policy documents. The factors listed are as follows:

Context: This refers to the sources of the document, and the context in which it was produced (historical background of the document and the purpose behind its production).

Recommendations: The rationale behind the recommendations made, also the conception of the recommendations according to the policy.

SKAV: What skills, knowledge, attitudes and values are targeted to be achieved through the policy recommendations; how are the recommendations made going to be achieved practically?

Implementation: Measures to be taken to ensure successful implementation of the recommendations made.

For the purpose of this study, the third factor in the list, which addresses the skills, knowledge, attitudes and values that are targeted to be achieved through the policy recommendations, was used. Other factors were exempted from the study because the study is primarily concerned with policy practice only which was considered under this section of the analytical tool. Specifically, the study is concerned with skills and knowledge arms of the SKAV. The CHE (2015), ECSA (2017) and electronics engineering handbook (2017 edition) were cross-examined using Jansen and Reddy's (1994) analytical tool. The purpose was to ascertain what the documents foregrounded about skills and knowledge related to troubleshooting in electronics engineering programmes. The information retrieved and analysed from these documents were only information relevant to the study as care was taken not to extract beyond the relevant information (Bell, 2014). Documents analysed gave insight into what was foregrounded on the place of troubleshooting in the undergraduate electronics engineering programme.

4.5.3 Phenomenographic analysis of interview data

Initial analysis involved the process of becoming familiar with the transcripts as a whole. Each transcript was read and re-read several times in an attempt to reveal broad differences in pools of meaning. In the phenomenographic approach to data analysis, the transcripts are the focus of the analysis. The set of categories that are derived from the data as the results is not determined in advance, but emerges from the data, in relationship with the researcher (Åkerlind, 2012). Chunks of text, or potentially relevant quotes, were then separated from the transcript and analysed for their meaning. This served as a means of decontextualising the quotations from the individual respondents and was used to further identify common pools of meaning or categories and further reveal differences between the categories.

In analysing research data using the phenomenographic approach, the structural and the referential aspects of the studied phenomenon were essential. The following were adopted: the "what aspect" (the referential aspect) and the "how aspect" (structural aspect) of the phenomenon. In this study, the structural aspect was divided into two aspects, the "how aspect", which depicts how the phenomenon is being described by the participant, and the"why aspect", which depicts "what informs" the intention for the how action, depicting what informs how the phenomenon was described. When the participants narrate their story: what do they narrate, how do they experience what they narrate and what informs what they narrate about their experience of the phenomenon?

4.5.4 Phenomenographic analysis procedures

The whole text was read carefully. The texts of individual participants were read again and divided into smaller sizes to mark out where the respondents gave answers to the interview questions. The three queries of "What", "How" and "Why" explained above were used to elicit the categories in individuals' responses. That implies that, for each chunk of quotes of a respondent in the passages, I looked for the "what" in the participant response, focused on what the narration was about the phenomenon in question (e.g. design, troubleshooting, debugging in software), "how" did he/she describes his/her way of doing it (e.g. identifying problems in design, or structuring project completion time) and why did he do it that way – the intention, the explanation given for the action, (e.g. to highlight troubleshooting stages in design). Then these descriptions were grouped into categories based on similarities and differences observed to formulate the categories of description. These categories of description were then organized hierarchically to find an outcome space which became the theme of results that were discussed in the study. This process was done for all the answers given to the interview questions for research question one, and was repeated for other research questions two and three. While the description on the individual level was used to help clarify/refine the categories of description, it was not used to classify individuals belonging to any particular category. In other words, individual variation was not used in the description of the outcomes and themes that eventually emerged.

The analysis process was also guided by emerging understandings of how the act and outcomes of learning may be described (Marton & Booth, 1997). The particular focus inherent in phenomenography has produced two distinctive outcomes for any phenomenographic study namely; the categories of description and an outcome space (the major themes that emerged as findings of the study). In other words, the primary outcomes of investigation therefore are:

(i) Categories of description associated with troubleshooting in engineering. These capture the critical dimensions of what lecturers, laboratory instructors and students conceive as troubleshooting skills in electronics engineering programme, and
(ii) An outcome space which describes the relationships and interactions between the categories.

Each category of description represents one 'conception' or way of experiencing or being aware of or constituting the phenomenon of the place of troubleshooting in an electronics engineering programme and the way of conceptualizing electronics engineering education programmes. The categories of description were later synthesized into themes that represented the outcome space, the results of findings in the study. In order to arrive at the expected categories of description and outcome spaces for this study, the following processes of analysis were followed for each research questions.

4.5.5 Analysis of Research Question 1 results - The referential aspect

Research question 1: *Is there a place for troubleshooting in university electronics engineering programme?*

The place of troubleshooting was initially perceived differently and categorized into two; firstly, those that agreed that there is a place and their general understanding of such, secondly, those that affirmed that there is no place and their general understanding. These responses were analysed using a descriptive bar chart to distinguish the two sections from each other.

Research question 1(a): *If yes, what is being foregrounded in university electronics engineering programme?*

The three queries of what, how and what informs aspects adopted as described in section 4.7.4 above were used to understand and interpret the data. The data were interpreted as follows:

(i) The "What" aspect: What was actually foregrounded by each participant about troubleshooting, that is, what is the participant focusing upon in their talk;

(ii) The "how" aspect: How did the participant do the event, the focus of the description given about the action, that is place of troubleshooting in electronics engineering and,

(iii) The "why" aspect: What informs the how or the reason for the description?

Under this question, three qualitatively different categories of "what" aspects, six of "how" aspects and six of "what" informs aspects were elicited and will be discussed later.

Research question 1b: *If not, what is being foregrounded in the university electronics engineering programme?*

The same procedure as above (1a) was used; five different categories of descriptions of the "what" aspects emerged, seven of the "how" aspect and seven of the "what informs" the how.

4.5.6 Analysis of research question 2 results: The structural aspect (the how?)

Research question 2 was analysed as follows.

Research question 2: *How is the university electronics engineering programme being enacted by the lecturers, laboratory technicians and students?*

Three queries were also adapted as used in research question (1a) above to understand how troubleshooting is being enacted by this section. The set of queries used to interrogate this question are presented below:

(i) The "what" aspect: This refers to the "categories" identified the approach of enactment of the electronics engineering programme;

(ii) The "how" aspect: this refers to the categories identified as how the electronics engineering programme was enacted;

(iii) The "why" aspect: this refers to the categories on what informs the enactment of the electronics engineering programme in a particular way.

Five qualitatively different categories of the "what aspects" are described; seven of how it is being described and seven of what informs the description.

4.5.7 Analysis of research question 3 results: The structural aspect (What informs/the intention)

Research question three was analysed as follows.

Research question 3: *What informs how electronics engineering programme is being enacted in the university?*

The analysis followed similar use of three queries.

(i) The "what" aspect: This refers to the what category of "what informs" how the electronics engineering programme was enacted;

(ii) The "how" aspect: this refers to the how category of "what informs" how the electronics engineering programme was enacted;

(iii) The "why" aspect: this refers to the why category of "what informs" how the electronics engineering programme was enacted.

Two categories of description emerged on each of the aspects of this section.

4.6 The place of troubleshooting in an electronics engineering programme

In order to locate the place of troubleshooting in the electronics engineering programme, the three domains in Lefebvre's theory of production of space were employed. The three domains used in this study comprise the conceived space (the policy), the perceived space (institutional curriculum and instruction) and the lived space (fourth-year students). According to Lefebvre, the three domains must internally relate with each other at unity to produce space, otherwise there will be inequity in the production process (Lefebvre and Nicholson-Smith, 2012). In other words, to locate the place of troubleshooting amongst the three domains in the electronics engineering programme, the outcomes of findings from the analysis of data were treated as they internally relate to the system as a whole. The outcome from the conceived space was compared with that from the perceived and the lived spaces. In Lefebvre's theory, a place is located where there is a high sense of practice, a regular practice of an object in space. In other words, the place of troubleshooting is traced to where it exhibits a high sense of place amongst the three domains in the electronics engineering programme.

4.7 Ethical considerations

According to Collier-Reed and Ingerman (2013), phenomenographic studies data are collected predominantly in two ways, through an interview or through text written by the participants in a response to a specific interview question. Interview data was employed in this study; hence conducting the studies requires attention to ethical concerns. Cohen, Manion, and Morrison (2011) assert that the major ethical dilemma in research is that which requires researchers to strike a balance between the demands placed on them as professionals in pursuits of truth, and their subjects' right and values potentially threatened by the research. Ethical challenges for researchers, if not considered, can become problematic if not addressed. In order to address such challenges, there are ethical principles that researchers must take as their guidelines. Cohen, Manion, and Morrison (2011) present the following principles which were adopted during this study:

(i) Observe protocol: relevant committees and authorities were consulted and officially informed before commencement of the data collection. Gatekeeper and Ethical Clearance letters were obtained from the appropriate university authorities. The informed consent letter was given to each of the participants to secure their permission before the generation of data commenced.

(ii) Privacy: to avoid violating the issue of privacy during data generation period, the participants were requested to choose the settings and place of interview. The participants had the right to withdraw at any stage of participation, not to answer questions and to limit the time needed for participation.

(iii) Anonymity: the essence of anonymity is that the information provided by the participants should not in any way reveal their identity. The participants were informed through the consent form that their identity would not be disclosed from the information they provided during the interview, rather, pseudonyms and codes were used to represent each of them. This was strictly adhered to during the course of interview, data gathering and analysis according to the university ethics. Participants were represented with the use of pseudonyms and codes. The lecturers and laboratory technicians were represented as P01, P02 to P06, while the students were referred to as ST01 to ST06.

(iv) Confidentiality: this is another way of protecting the participants' rights to privacy by making sure that information from the participants were not disclosed to another participant in any way that might identify that individual. I made sure that all participants were treated with confidentiality in all the information supplied during data generation period. They were assured of confidentiality in the informed consent presented to them before the commencement of the study.

4.8 Validity and reliability

According to Pandey and Patnaik (2014), researchers in the qualitative paradigm consider the concept of credibility when referring to the validity and reliability of a research. The credibility of a research study deals with how compatible are the findings with reality, whether the study measures what is actually intended to measure or there are digressions (Lincoln, Lynham, & Guba, 2011). Credibility increases the trustworthiness of qualitative research.

Phenomenographic research does not concern itself with reliability but explores credibility and validity. The main issue of credibility in a phenomenographic analytic approach is based on the relationship between the data obtained from interviews and the categories for describing the ways in which people experience a certain phenomenon (Sjostrom & Dahlgren, 2002). To ensure credibility in the study, data were carefully transcribed; the categories of descriptions were carefully selected to describe the similarities and differences that emerged. Excerpts from the interviews were provided to support the categories described. The excerpts were relevant to the categories of description that emerged from the interview. Each part of the research processes were described from the research questions, the interview questions, data collection and the phenomenographic systematic analysis of data collected.

To ensure the credibility of the categories established in this study, analyst triangulation was also used as my supervisor interrogated the data alongside with other staff in the cluster of Science and Technology Education. This step provided a check on selective perceptions that may arise from a researcher's selective perception of data and illuminated blind sports that characterized interpretive analysis. The critical issues in the data were appropriately identified, recorded and applied where necessary to arrive at reasonable categories of description and outcome space.

On credibility in phenomenographic research, Marton (1988, p. 148) argued that in case of phenomenographic analysis, the issue of replicability is not justified or even desirable. According to her, the categories of description could be referred to as constituting the "discovery" of the study. The categories of description provide the original finding of the study and the discoveries do not have to be replicable (Sjöström & Dahlgren, 2002). But once the categories have been found, it must be possible to reach a high degree of intersubjective agreement concerning their presence or absence, if other researchers are to be able to use them. Replicability is defined by Marton (1988) as introducing intersubjective agreement. This implies that another researcher can apply the proposed categories and classify the excerpts to determine the degree of concordance between the two outcomes. If the degree of concordance is acceptable, then the categories of description is replicable in that case, otherwise it is not.

In terms of validity, three types of validity checks highlighted in phenomenographic research by Booth (1992, p. 65) are:

(i) content-related validity checks – the research has to be based on a comprehensive understanding of the subject content;

(ii) methodological validity checks – the phenomenographic approach should be infused into the study from the data collection stage, through the analysis to the presentation of the results;

(iii) communicative validity checks – the study should seek feedback from other populations represented by the interview sample and intended audience for the findings.

On content validity checks, as an undergraduate and postgraduate student in electronics technology and a lecturer in electronics courses, as mentioned in chapter one (section 1.2), I was familiar with the context of troubleshooting in electronics. I had interacted with undergraduate electronics students and had consulted relevant text materials on troubleshooting in electronics courses.

With respect to methodology check, the phenomenographic approach was involved in all the stages in the study. The research questions were crafted to reflect the three aspects constituted by phenomenographic methodology – the referential (the what? question), the structural (internal horizon – the how? question) and the structural (external horizon – the why? question). Data were collected based on interview questions to address these three aspects. Data analysis was also characterized by using the three queries of "what", "how" and "what informs", to interrogate, interpret and analyse the responses from the respondents. The categories of description were derived from the interpretations of the queries and were prior to the outcome space, which was the end result of the analysis.

According to Arkerlind (2012), phenomenographic research does not seek feedback from interviewees because it is regarded as inappropriate for phenomenographic validity checks. The reasons advanced for this standpoint is that the interpretations of findings and results are not based on individual participants' views, rather, it is made on a collective basis. The researcher sought feedback from other lecturers, technologists, and experts from visiting industries during the open-day ceremony. The open-day ceremony was a platform whereby all final-year electronics engineering students displayed and exhibited their completed Final Year

Design Projects to external examiners, parents, sponsors and the public. The researcher interacted with students and staff present to check their responses to the findings from the data already collected and analysed. In addition, staff from the Cluster of Science and Technology were consulted on the analysed data for feedback on possible bias.

4.9 Rigour

The results of the data collected were analyzed and the findings of this research were open to critique by the participants themselves, as well as by other selected academics and researchers in this field of study. This is to ensure the soundness and accuracy of the findings and conclusions reached, as emphasized by Nixon & Power (2007). Access to the participants was one of the challenges that came up during the process of data generation. Some of the participants had a very tight schedule, making it a bit difficult to get their attention for interview sessions. However, I had to work into their schedule to get their attention. The interview session had to be broken into segments of two or three contacts to be able to collect a rich volume of data from the participants. Some of the participants, especially the lecturers, were very difficult to reach; I had to send reminders via e-mail several times to schedule appointments with them. The student participants equally posed some challenges in reaching them for the interview, especially the focus group session of the interview, as most of them had different engagements on their schedule. It took a long time to assess a few of them and short periods as well as they were busy attending to their design project tasks.

4.10 Conclusion

This chapter presented a detailed account of the analytical and theoretical frameworks of the study. The methodology of enquiry was clearly expounded with from the design, through data generation to data analysis and the finding the results. The phenomenographic analytical framework was carefully linked to the use of Lefebvre's theory of space as an overarching theoretical framework, which aided in locating the place of troubleshooting in the electronics engineering programme. These has laid a sound foundation for the presentation of results of the study. The results will be presented and analysed in the next three chapters 5, 6 and 7.

CHAPTER 5

ANALYSIS OF RESEARCH QUESTION ONE

UNDERSTANDING WHAT WAS FOREGROUNDED IN THE UNIVERSITY ELECTRONICS ENGINEERING PROGRAMME

5.0 Introduction

This study is concerned with understanding the place of troubleshooting in undergraduate electronics engineering education programmes. Despite the fact that troubleshooting is considered as an integral component of an engineering career and as a professional skill (Dounas-Frazer & Lewandowski, 2017; D. Jonassen, 2011; D. Jonassen et al., 2006) conventional/traditional engineering education programmes do not emphasise real-workplace troubleshooting problems (Male, 2011). While certain processes in engineering practice, such as design and project management, have received much attention, and have even been extensively studied in research, certain workplace required skills such as troubleshooting hardly receive attention (Trevelyan, 2007). The concern of this study is that troubleshooting is not explicitly articulated in electronics engineering programmes. It is unclear what attention and place various stakeholders in engineering education give to troubleshooting in electronics engineering programmes. This chapter seeks to provide an insight to these issues from an empirical perspective using phenomenographic analysis by answering the following first three questions:

1. Is troubleshooting being accommodated in the electronics engineering programme?

- Policy documents - CHE and ECSA documents?
- University electronics engineering handbook?
- Lecturers - electronics engineering lecturers?
- Technicians - electronics engineering laboratory technicians?
- Students - fourth year electronics engineering students?

a. If so, what is foregrounded in the electronics engineering programme?
b. If not, what is foregrounded in the electronics engineering programme?

The above questions will be addressing the first research question of the study. This section of analysis will be looking at documents analysis and interview responses from respondents in the study. The analysis pattern will be as follows; (i) Policy document on qualification standards for the Bachelor of Engineering from the Council on Higher Education

(CHE); (ii) Engineering Council of South Africa (ECSA) document; (iii) University electronics engineering handbook (curriculum) document; interview data analysis from (iv) electronics engineering lecturers (v) electronics engineering laboratory instructors and (vi) fourth year electronics engineering students.

This chapter of the analysis is divided into six main sections according to the source of data collected to answer the three questions posed above, namely, sections 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6. In each of the sections, data generated from the study will be presented and analysed in accordance with the research questions raised.

5.1 Council on Higher Education document analysis

Research question 1

Is troubleshooting accommodated in the university electronics engineering programme?

Document Analysis

The analyses of the policies presented in this section are done by using the Jansen and Reddy's (1994) document analytical tool. The tool suggests the following four factors to be considered in analyzing policy documents.

Context: This refers to the sources of the document, and the context in which it was produced (historical background of the document and the purpose behind its production).

Recommendations: The rationale behind the recommendations made, also the conception of the recommendations according to the policy.

SKAV: What skills, knowledge, attitudes and values are targeted to be achieved through the policy recommendations; how are the recommendations made going to be achieved practically?

Implementation: Measures to be taken to ensure successful implementation of the recommendations made.

For the purpose of this study, the analysis simply focused on the third factor which directly talks to the skills, knowledge, attitudes and values that are targeted to be achieved in a programmes.

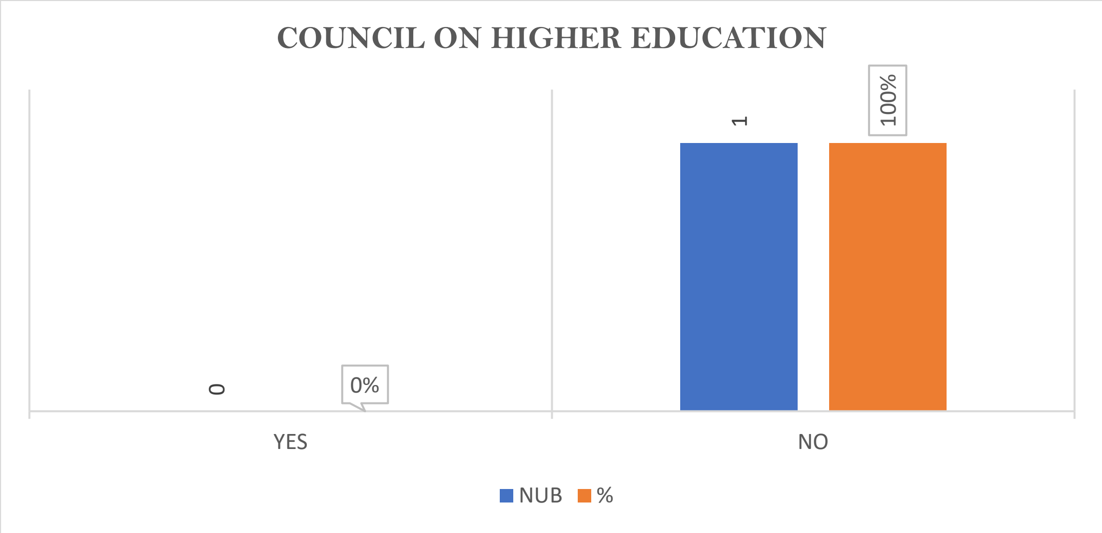


Figure 6: Chart on Council on Higher Education document: number of participants

The figure above indicates that troubleshooting is not accommodated in the government White Paper document for electronics engineering education. The CHE (2015) document on university engineering programmes consulted did not make reference to the troubleshooting skill as being required as one of the hard skills for engineering programmes in South Africa. Those aspects that could directly or indirectly speak on troubleshooting skills such as maintenance, diagnosis, troubleshooting were not addressed in the policy.

The policy document is divided into two types of Bachelor's Degrees in engineering education, namely general and professionally oriented Bachelor's Degrees structured as a 360-credit and 480-credit qualification Bachelor's Degree respectively. The primary purpose of both the general and the professional Bachelor's Degree is to provide a well-rounded, broad education that equips graduates with the knowledge base, theory and methodology of disciplines and fields of study, and to enable them to demonstrate initiative and responsibility in an academic or professional context (CHE, 2015). The professional Bachelor's Degree prepares students for professional training, post-graduate studies or professional practice in a wide range of careers. Therefore it emphasizes general principles and theory in conjunction with procedural knowledge in order to provide students with a thorough grounding in the knowledge, theory, principles and skills of the profession or career concerned and the ability to apply these to professional or career contexts. The degree programme may contain a component of work-integrated learning.

5.1.2 Research question 1(a) – not applicable for this section

5.1.3 Research question 1(b)

If not, what is being foregrounded in the CHE document?

The following skills and knowledge levels were targeted and foregrounded for engineering education, inclusive of electronics engineering programmes.

Skills required for graduates	**Knowledge required to demonstrate**
Ability to identify, formulate, analyse and solve complex engineering problems creatively and innovatively	A systematic, theory-based understanding of the natural sciences applicable to the discipline
Ability to apply knowledge of maths, natural sciences, engineering fundamentals and engineering speciality to solve complex engineering problems.	Conceptually-based mathematics, numerical analysis, statistics and formal aspects of computer and information science to support analysis and modelling applicable to the discipline
Ability to perform creative, procedural and non-procedural design and synthesis of components, systems, engineering works, products or processes	A systematic, theory-based formulation of engineering fundamentals required in the engineering discipline
Ability to demonstrate competence to use appropriate engineering methods, skills and tools, including those based on Information Technology.	Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline
Ability to demonstrate competence to communicate effectively, both orally and in writing, with engineering audiences and the community at large.	
Ability to demonstrate critical awareness of the sustainability and impact of engineering activity on the social, industrial and physical environment	
Ability to demonstrate competence to work effectively as an individual, in teams and in multidisciplinary environments.	
Ability to demonstrate competence to engage in independent learning through well-developed learning skill	
Ability to demonstrate critical awareness of the need to act professionally and ethically and to exercise judgement and take responsibility within own limits of competence	
Demonstration of knowledge and understanding of engineering management principles and economic decision-making	

Source: Qualification Standard for Bachelor of Science in Engineering (CHE, 2015)

Table 5: Skills and knowledge required for electronics engineering programmes

5.2 Engineering Council of South Africa (ECSA) document analysis

5.2.1 Research question 1

Is troubleshooting accommodated in the university electronics engineering programme?

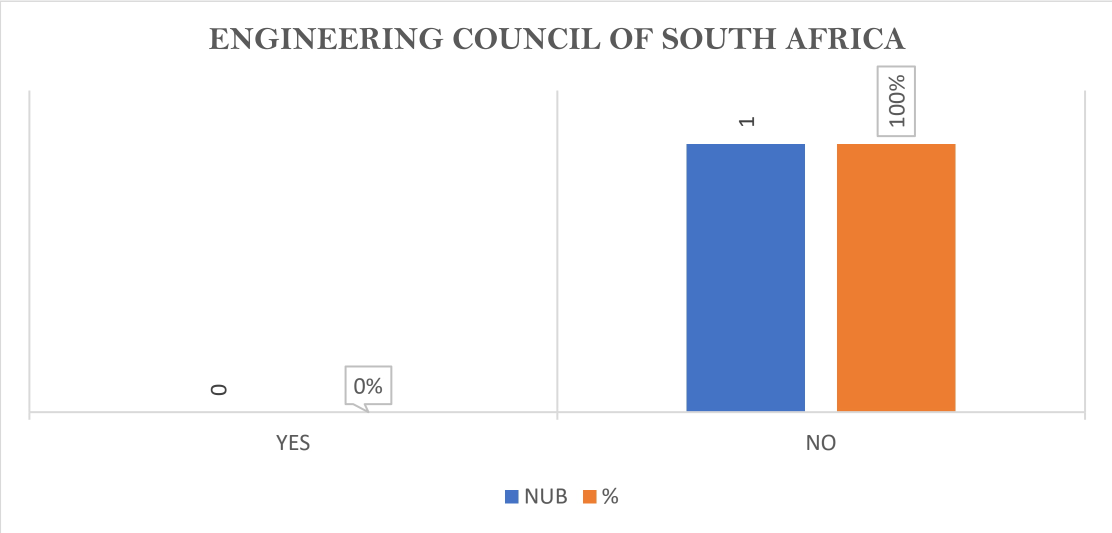


Figure 7: Chart on Engineering Council of South Africa document

The figure above indicates that troubleshooting is not accommodated in the ECSA White Paper document for electronics engineering education. The ECSA (2017) document on university electronics engineering programme consulted did not make reference to the troubleshooting skill as being required as one of the significant hard-core skills for electronics engineering programmes in South Africa. Those aspects that could directly or indirectly speak on troubleshooting skills such as maintenance, diagnosis, troubleshooting were not addressed in the document. This discovery was also underpinned by the response of an ECSA member interviewed during data generation for the study.

5.2.2 Research question 1(a) – not applicable for this section

5.2.3 Research question 1(b)

If not, what is being foregrounded in the CHE document?

In order to answer this question further, a member of ECSA was interviewed. The ECSA member stressed that the generic engineering graduate skills stipulated in the ECSA document did not include troubleshooting skills as one of the requirements for undergraduate electronics engineering education programmes. The pillars of engineering graduate skills (also referred to as generic engineering skills) are considered integral to the engineering profession. These are the stipulated outcomes in the accreditation criteria for engineering education programmes which ECSA subscribe to as standard for engineering education in South Africa. The following pillars of electronics engineering education which are inclusive of the eleven generic electronics engineering skills from ECSA document were highlighted:

- an ability to apply knowledge of mathematics, science, and engineering;
- an ability to design and conduct experiments, as well as to analyse and interpret data;
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
- an ability to function on multidisciplinary teams;
- an ability to identify, formulate, and solve engineering problems;
- an understanding of professional and ethical responsibility;
- an ability to communicate effectively;
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context;
- a recognition of the need for, and an ability to engage in life-long learning
  a knowledge of contemporary issues; and
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. (ECSA, 2017).

It is significant to note that there is similarity and commonality in the skills and knowledge requirements for electronics engineering graduates from both CHE policy document and ECSA document. A cross analysis of the two documents reveals the placement of emphasis on solving complex engineering problems and engineering design skills. Theory-based knowledge of science, mathematics and fundamentals of engineering are mostly emphasized.

5.3 University electronics engineering handbook (the discipline curriculum)

5.3.1 Research question 1

Is troubleshooting accommodated in the university electronics engineering programme?

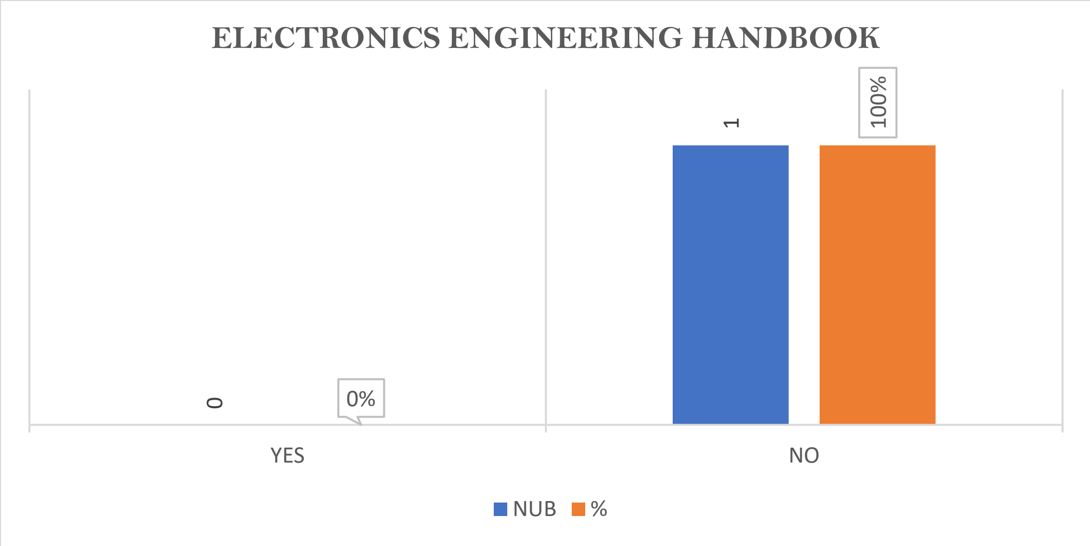


Figure 8: Chart on university electronics engineering handbook

The chart above indicates that troubleshooting is not accommodated as a specific component of any of the courses offered in electronics engineering programme in the university. The content of the curriculum does not in any way recognize troubleshooting as a skill to be learned or taught. The pedagogies focused mainly on scientific approach, theory-based problems, complex engineering problem solving and design process and product among others.

5.3.2 Research question 1(a) – not applicable for this section

5.3.3 Research question 1(b)

If not, what is being foregrounded in the university electronics engineering programme curriculum?

The university electronics engineering handbook provides insight to this question. The content of the handbook reveals the following courses to be offered, among others, by undergraduates electronics engineering students in order to acquire engineering skills; these were being foregrounded as integral to the program:

Electronic Design Project – with emphasis on performing individual design to an agreed specification;

Electronics design 1 and 2 – with emphasis on conducting group design studies and seminars on selected topics of interest to electronics engineering;

Electronics design 3 - with emphasis on conducting group design studies and seminars on selected topics in electronics engineering.

Vacation Work	- is a 13-week practical skills' acquisition period which enables the students to work in a realistic electronics engineering environment.

5.4 Analysis of lecturers' responses

5.4.1 Research question 1

Is troubleshooting accommodated in the university electronics engineering programme?

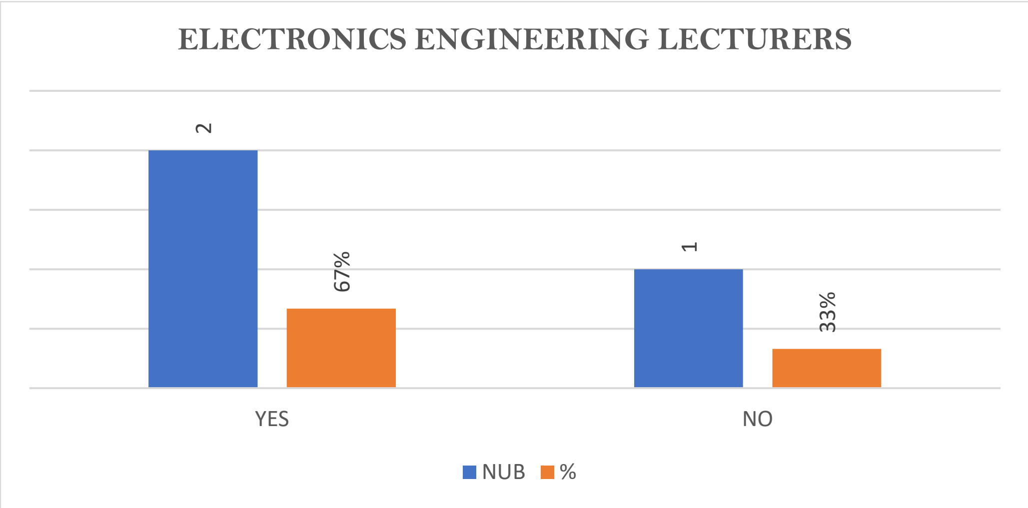


Figure 9: Analysis of lecturers' responses

Figure 9 compares the frequency rates of the two types of responses to the question: *Is troubleshooting being accommodated in the electronics engineering education programme at your institution?* As illustrated in the figure above, two (2), representing 67% of the participants, responded that troubleshooting was, indeed, accommodated in the electronics engineering education programme, as opposed to the one (1) representing 33% that opted for the contrary. It is significant to note that the responses of those that affirm its accommodation are higher than those with contrary opinion. This lead to focusing on research question 1a to elicit what is foregrounded in the electronic engineering programme.

5.4.2 Analysis of research question 1(a)

If so, what is being foregrounded by the lecturers?

With respect to those that responded affirmatively, the analysis of the participants' responses to the question on whether there is space for troubleshooting in the electronics engineering programme, pointed to the following three queries:

1. The "What" aspect: What was actually foregrounded by each participants about troubleshooting, that is what event is the participant talking about;

2. The "how" aspect: How the participant did the event, the focus of the description given about the action, that is the place of troubleshooting in electronics engineering and;
3. The "why" aspect: What informs the how or the reason for the description?

The classifications of response for the participants that fall under this category on research question one (1a) are shown in Table 6.

What was foregrounded?	How?	What informs the how?
Approach *"The significance of teaching students how to think"*	Uniqueness of the approach	To respond to the different sectors of the engineering industry
	Usefulness of the approach	To have the ability to solve any engineering problem, not specific one
	Instils creativity	To produce self-regulated learners
Time *"Delivering of Curriculum"*	Structures project completion	To introduce students to design process
Design *"Providing the context for problem solving"*	Identifies problem in design	To highlight troubleshooting stages embedded in design
	Diagnosis /finding faults in design	To reflect implicit troubleshooting practice in design

Table 6: Classification of responses under the "yes" category

With regard to "what was foregrounded", the following three categories of descriptions were elicited, namely:

- The approach;
- The time;
- Design.

Approach

With regard to the "**what**" aspect, this category of description was elicited, namely:

The significance of teaching students how to think

Out of the six staff participants that took part in the interview, two of them spoke about the "approach" in addressing the question on whether troubleshooting was accommodated in electronic engineering or not. P01 specifically stressed the differences between the teaching approach adopted by conventional university engineering instructors and that used by a university of technology. As reported by him, the teaching approach differs from the standard teaching method which is direct, conventional and solution-driven. The approach of teaching which involved direct interactions between the instructor and the students through lectures and laboratory manuals on the phenomenon of troubleshooting were not encouraged in the programmes. Rather, their approach teaches the students how to think and work their own way towards the learning of troubleshooting**.** The approach was based on a certain philosophy peculiar to electronics engineering education programme at the university. The philosophy is such that the engineers' perspective of problem solving is different to that of a technologist or a technician who are taught directly on how to solve well-defined troubleshooting problems. The engineering educators teach thinking skills and this differentiates the university from those of a university of technology in terms of what they offer to their students. The participant reacted to this difference by giving an example of his second year practical example in the university. He described the experience by touching on the instructions given to him by his former lecturer, on the difference between the domain of problem solving ability of university of technology and that of conventional university. The former would solve a direct, conventional, well-structured engineering problem almost immediately, while the later takes much longer time to solve the same problem simply because he/she was not taught that approach. His thought was illustrated in the excerpt below:

> *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. There is a difference and the difference is between the Natal technical on the road and the Natal University (P01, Interview, October 26, 2016).*

Similarly, he went further, expatiating as follows:

> *This is the philosophy behind it, if you go to a person that study technical, and you ask him, design for me this power supply with this specifications. He would do it beautifully for you; he knows how to do this thing properly. Alright, you ask the same question from an engineer from Natal University, he wouldn't know how to do it, he would take much longer to make it, he was not taught that approach (P01, Interview, October 26, 2016).*

With regard to the "**how**" aspect, the following three categories of description were elicited, namely:

- The uniqueness of the approach;

- The usefulness of the approach;
- Instils creativity;

The uniqueness of the approach

By the response of one participant (P01), the idea that the approach was unique to the electronics engineering programme being undertaken by UKZN was underpinned. It was highlighted in the uniqueness of the approach, which is different from a standard teaching approach. The approach focused on students' being given a design problem to solve without being taught how to solve the problem until they encountered and discovered the problems on their own and then they are reinforced by instructors to solve it. This is different from what is found in the university of technology where students were taught how to solve specific electronics laboratory and practical problems. The uniqueness of the approach is reflected in the excerpts below:

> *It (the approach) is different from standard teaching methodology, the difference between the Natal technical on the road and the Natal University (now UKZN), in Natal technical, they will teach you the solution; we don't teach them solutions but they would figure it out (P01, Interview, October 26, 2016).*

The usefulness of the approach

P01 also pointed to the usefulness of the approach, which helps students to solve new engineering tasks. He further stressed that the approach enables engineers to solve new task problems better than the task he/she has seen or been exposed to previously. This is often referred to as an ability to handle ill-defined problems as illuminated in the excerpt below:

> *And what is the usefulness of this approach. The usefulness of this approach is very simple, if I ask both of them, to do a new task, the thing they have never seen before, the engineer will still solve it, because every task for him he has never seen it before. The guy from the technical will say we will not progress and I cannot do it (P01, Interview, October 26, 2016).*

The approach instils creativity

Furthermore, the approach instils creativity in the students' learning style. It demands a lot from the student through personal experience and little supervision. But the experience was beneficial to the extent of making them creative in engineering practice as described in the excerpt highlight as follows:

So there is creativity that we instil in our students through this methodology. It is in some ways a harsh methodology because it demands more of a lot from students. I know this very well because this approach goes on many in our design process, not lectures and most of them learn this most. And when we ask them, how did you learn this most and they will tell you, we learnt it in our design and how did you learn, they learn through personal experience and supervision. They are not actually taught, and that's where most of the problem solving skills and troubleshooting skills are acquired (P01, Interview, October 26, 2016).

Tutor 01 described the approach as a harsh methodology because students had to give a lot of attention to learn the design process in engineering.

With regard to the "**why**" aspect, the following three categories of description were elicited, namely:

- To respond to the different sectors of the engineering industry;
- To have the ability to solve any engineering problem, not specific one;
- To produce self-regulated learners;

To respond to the different sectors of the engineering industry

The reason advanced by one of the participants (P01) for the unique approach was to prepare electronic engineers for their workplace experience and make them respond to a generic function such as engineering design. It is considered unique and it is in response to different sectors of the electronics engineering industry and professional practice that distinguish the role of graduates from conventional engineering universities (UKZN in this case) from that in the universities of technology. This is illustrated in the excerpts below:

To give you an example, we are not saying that it is wrong to teach specific methods and to teach specific approaches, we are not saying it is wrong. That is fine and it must exist, the discipline needs this, the field needs it but we are addressing in our department a different sector of the industry (P01, Interview, October 26, 2016).

To have the ability to solve any engineering problem, not specific o**ne**

P01 also pointed out that this unique teaching approach in electronic engineering programme is useful to the students so they would have the ability to solve any electronics engineering problems, and not just specific ones in troubleshooting.

So the approach here at Natal University was certainly to give people the ability to solve any problem and that is why we didn't try to teach them any specific problem *solving method, because when you restrict your thinking and analytical skill to the scope of your formerly taught materials, you will not be creative, so we didn't formally teach them (P01, Interview, October 26, 2016).*

To produce self-regulated learners

The participant's emphasis was that the unique approach, which is significantly useful to engineering profession, would reinforce students' ability to think intuitively on their own when they encounter problems, seek for solutions, be creative and solve the problem in a self-regulated manner. The following excerpts corroborate the issues raised above:

That is the kind of approach, so in a sense, the student has to be self-started, because it's a harsh approach (P01, Interview, October 26, 2016).

Time

With regard to the "**what**" aspect, this category of description was elicited, namely:

Delivering of curriculum

With respect to time, one participant *(P02)* out of the two in this section captured time spent by students to deliver their final year design project work as providing a place and space for students to encounter and learn troubleshooting skills. The excerpt below speaks to this view:

Students are given six months to deliver their final project work apart from the individual and group projects (P02, Interview, October 25, 2016).

With regard to the "**how**" aspect, this category of description was elicited, namely:

Structuring project completion time

P02 explained that there is proper structuring of laboratory practical and project completion time. According to him, this include assigning four science practical in the first year, eight laboratory practical tasks in the second year, eleven in the third year, and six in the fourth year. Students are also assigned two individual and three group design projects. The final year project is given a specified completion time, hence, troubleshooting is achieved within a scheduled period. It is scheduled to be completed within the period of six months. The breakdown of the structure is shown in the excerpt below:

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 (P02, Interview, October 25, 2016).

With regard to the "**why**" aspect, this category of description was elicited, namely:

To introduce students to the design process

P02 further foregrounded that students would learn the process of design and troubleshooting in stages and during the specified time. According to this participant, from the highlighted excerpt above, the first three months of the design project refer to the survey stage while the remaining three to six months are tagged as the design stage. The two stages should avail the students the opportunity to learn how to troubleshoot.

Design

With regard to the "**what**" aspect, this category of description was elicited, namely:

Providing the context for problem solving

With regard to design, the two participants in this section, P01 and P02, pointed to the fact that students are engaged with a design and assembly process which incorporates troubleshooting. All of these tasks and experiences usually take place within the university context. Design is regarded as the complete process of producing hardware or an artefact of expected specification for the solution of a given engineering problem. In realizing the objective of design in engineering, troubleshooting is assumed to be incorporated and learned particularly in problem solving which is taught by default. The concept of design came up from the participant as shown in the excerpt below:

> *So when they are designing and assembling these components on the board (P02, Interview, October 25, 2016).*

Similarly, it was corroborated by P01 as follow:

> *I can elaborate on this. In some cases, let me start in a simple way, with specific aspect of circuit design and circuit theory. Let's say in second year we started with resistance network and of course, the problem solving is done and it's practically done because we go through circuit analysis, we go through the whole formal process of teaching. Although we don't identify any section as problem solving, we are teaching them problem solving by default (P01, Interview, October 26, 2016)*

With regard to the "**how**" aspect, the following two categories of description were elicited, namely;

- Identifying problems in design;
- Diagnosing (finding) faults in design.

Identifying problems in design

What is being underpinned by the two participants on "how" troubleshooting was embedded in the design aspect of electronics engineering programme was reflected in various forms. These occur by taking students through the process of design, and identifying possible problems and faults made by the students. It could be hardware, software or mechanical problems on an electronics design project. When students encounter such problems, it prompts them to make consultations with their colleagues and instructors; in that process the staff participant assumes the students learn the process of problem identification and how to troubleshoot. The how is reflected in the excerpts below:

> *.....then when they are facing some problems and then what happens, they come to me and can also take some help from their friends (P02, Interview, October 25, 2016).*
>
> *We are going through examples with them in resistance network. And again in the third year, we do transistor circuit to basic transistor circuit, and we go through design with them (P02, Interview, October 25, 2016).*

Diagnosing (finding) faults in design

Furthermore, as the students' encounter problems, they make fault finding efforts in design, hence, the participant assumed learning the troubleshooting art is achieved. This indicates that there is fault finding in design, which is one of the components of troubleshooting. As shown in what the participant highlighted.

> *Then we make some troubleshooting efforts like what is the problem?(P02, Interview, October 25, 2016).*

With regard to the "**why**" aspect, the following two categories of description were elicited, namely:

- To highlight troubleshooting stages embedded in design;
- To reflect troubleshooting practice in design.

To highlight troubleshooting stages embedded in design

The two ideas highlighted here were derived from the participants' responses on "what informs" the reason why design incorporates troubleshooting in electronics engineering programme in a particular unique way different from the conventional way.

> *At that time we start from the components, we check the basic components. Are the components ok, is it burnt component, is it destroyed components?*

We also check all the components separately. Then they will check the modules, yes sir the left module is working, yes sir the middle module is working, right-hand side module is working then we have to connect again (P02, Interview, October 25, 2016).

To reflect implicit troubleshooting practice in design

The participant stressed firstly that students learn the design process in stages, while the process is in progress; troubleshooting practice is highlighted and embedded in the design. Secondly, faults that emerge, are diagnosed and are solved in design stages reflect several instances of troubleshooting practice while they get involved in the design process. The response was established in the excerpt below:

So the troubleshooting comes up as they engage in their work (P02, Interview, October 25, 2016).

5.4.3 Analysis of research question (1b)

If not, what is being foregrounded by the lecturers? (If troubleshooting is not accommodated)

With respect to the responses of participants with contrary views, the analysis on the question on what was being foregrounded in electronics engineering programme, if troubleshooting was not accommodated, pointed to the following three classification coding; the "what", the "how" and the "why" as described below:

1. The "what" aspect: This refers to "What" was foregrounded in the programme;
2. The "how" aspect: this refers to the how of what was foregrounded in the programme;
3. The "why" aspect: this refers to the reasons for the how of what was foregrounded in the programmes.

The classifications of responses for the second category of research question one is shown in Table 7.

What was foregrounded?	How?	What informs the how?
Engineering practicals *"The significance of practical"*	Having practicals frequently	To develop expertise in electrical circuits phenomenon
Organic troubleshooting *"Organic troubleshooting is implicitly embedded in the practical"*	Engaging with top-down approach/ intrinsic learning	To develop troubleshooting skills organically
Scope of engineering jobs is in design *"Engineering job stops at design"*	Designing and simulating	To distinguish engineering tasks form technician tasks

Table 7: Classification of lecturers' responses under the "no" category

With regard to the "what" was foregrounded, the following three descriptions were elicited, namely:

- Engineering practicals;
- Organic troubleshooting;
- Scope of engineering jobs is in design;

Engineering practicals

With regard to the "**what**" aspect, this category of description was elicited, namely:

The significance of practicals

Significantly, the participant pointed to engineering practicals as what is accounted for in electronics engineering programmes. While they shared the same view that the electronics engineering programme did not incorporate specific formal troubleshooting, the ideas that emerged from the participants' responses showed that, first, engineering practicals are considered integral and relevant to the engineering profession. Engineering practicals include regular semester by semester experiments in physical electronics and circuit construction principles at lower levels, and individual and group projects from third year, all through to the final year of the programmes. This point is underpinned by the excerpts below:

> *....specifically, that for example when they are doing practical, often engineers have practical right from first year to their fourth year (P03, Interview, October 25, 2016).*

Similarly,

> *"....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 (P04, Interview, October 24, 2016).*

Furthermore,

> *So we make sure students know how to use bread boards, 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 (P05, Interview, October 24, 2016)..*

With regard to the "**how**" aspect, the following category of description was elicited, namely:

Conducting practical projects and experiments

The participants stressed that the focus was on essential practical projects and experiments that were conducted for students. Engineering students are offered eleven laboratory experiments in physical electronics and electronics circuit construction. They also have two practical projects in their third and final year, one single (individual) and one group project. As presented in the excerpts below:

> *….their practical happen in the afternoon, and often that require to put together when they do experiment in physics or chem., or the most senior have to put circuit together (P03, Interview, October 25, 2016).*

Also,

> *When they are given the task, they are supposed to work in a certain way. And if it doesn't work in this specific way, they are required to be able to figure out though the knowledge of their theory, to figure out why it's not working (P04, Interview, October 24, 2016).*

Furthermore,

> *We have 11 different practical with certain tasks students have to do, they have to build and construct (P05, Interview, October 24, 2016).*

With regard to the "**why**" aspect, the following category of description was elicited, namely:

To develop expertise in electric circuits' phenomenon

The participant's response further pointed to the fact that the programme was intended to make electronic engineering students study basic electronics phenomenon and develop expertise circuit diagrams and construction. The pedagogical focus was on theoretical and conceptual understanding of fundamental engineering knowledge in problem-solving, as illuminated in the excerpts below:

> *To study a certain phenomenon, or study circuit, they often put the circuit together (P03, Interview, October 25, 2016).*

So also,

> *And they must know what to expect, they know the theory and know how to read the diagram. If you don't know how to read the diagram, then there is a problem, and you will always have a problem with fault finding. So the main thing you have to get is individual theory of the component and how to read the diagra*m *(P04, Interview, October 24, 2016).*

Organic troubleshooting

With regard to the "**what**" aspect, the following category of description was elicited, namely:

Organic troubleshooting is implicitly embedded in the practical

In the case of organic troubleshooting, students are given a little bit of reinforcement, but mainly, they learn the art through their self-efforts, as reported by one of the participants *(P03)*.

It was worth noting that organic troubleshooting in design was highlighted as what was also embedded in electronic engineering programmes. Organic troubleshooting is a natural, inherent and intrinsic style of learning how to troubleshoot, whereby students learn to deconstruct the process and practice of troubleshooting on their own. 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 (P03, Interview, October 25, 2016).*

With regard to the "**how**" aspect, the following category of description was elicited, namely:

Engaging with top-down approach through the help of demonstrators

The participant indicated that the focus was on the ability of students to work on their own informally using a top-down approach to troubleshoot difficulties in circuits through the assistance of demonstrators. This approach is referred to as a top-down methodology to problem-solving. A top-down approach operates by reducing the engineering system complexity, and by decomposing it into its constituent elements in an intrinsic manner. Starting with the system as a whole, the system is partitioned into smaller and smaller elements known as subsystems or modules and then components. As students engage in such processes, the troubleshooting art is said to be practised in an organic manner. This approach is said to be reinforced for the students as described by the participant below:

> *Is the power on, it's the power right, it's the component burnt. So it's working from top to down I suppose; the demonstrators during the practical will be on standby, they will be high skilled in the circuit, and they will then put the circuit together, they will show them to solve the problem and how to troubleshoot the circuit (P03, Interview, October 25, 2016).*

With regard to the "**why**" aspect, the following category of description was elicited, namely;

To pick up self-acquired troubleshooting skills

The participant further stressed that engineers pick up self-acquired troubleshooting skills while they work organically on assigned design skills. Since the process of top-down approach is self-consistent in engineering design, students are assumed to eventually pick up what is referred to as organic troubleshooting skills on their own without being specifically or formally taught. The excerpts below reflect the view described.

> *So that they pick it (the self-acquired troubleshooting skills) up; it's more organically touched right from their first year to fourth year;*

Troubleshooting is a requirement that they pick up in their training (P03, Interview, October 25, 2016).

The scope of engineering jobs is design

With regard to the "**what**" aspect, this category of description was elicited, namely:

"The job of engineering stops at design"

Two participants out of four, representing 50%, stressed the importance of the scope of engineering jobs to engineering students. According to them, engineering jobs have a delimitation of function that differs from that of technicians in terms of what they offer their students and their professional practice. This informs the contents of their learning at the conventional UKZN University. It is significant to note that participants in both the "Yes" and "No" categories agreed to the opinion that the job of engineers is delineated as design. It was illuminated by the excerpts below:

Normally engineering job stops at design; normally, that is where engineering jobs stops and then handed over to the technician to put together (P04, Interview, October 25, 2016).

With regard to the "**how**" aspect, this category of description was elicited, namely:

Designing and simulating

P03 further pointed out that the focus of the scope of training at the UKZN engineering programme was on designing and simulating, because this is where engineering jobs actually stop and are handed over to technicians to implement and maintain the produced electronics system or equipment.

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 (P03, Interview, October 25, 2016).

With regard to the "**why**" aspect, the following category of description was elicited, namely:

To distinguish engineering tasks from technician tasks

Emphasis was made by P03 that the scope of engineering jobs was restricted in such a way so as to distinguish between engineering tasks and technician assigned tasks in the industry. It is assumed that while engineers are saddled with basically designing and simulations, technicians continue with maintenance of engineering artefacts. This is why engineers should not be as bothered with specific troubleshooting problem-solving skills as revealed in the excerpt presented below.

Normally, that is where engineering jobs stops and then handed over to the technician to put together. In actual fact, the thing is, in actual fact (repeated) I wouldn't be surprised if technicians are taught troubleshooting more than engineers (P03, Interview, October 25, 2016).

5.5 Analysis of laboratory technicians' responses

5.5.1 Research question 1

Is troubleshooting accommodated in the university electronics engineering programme?

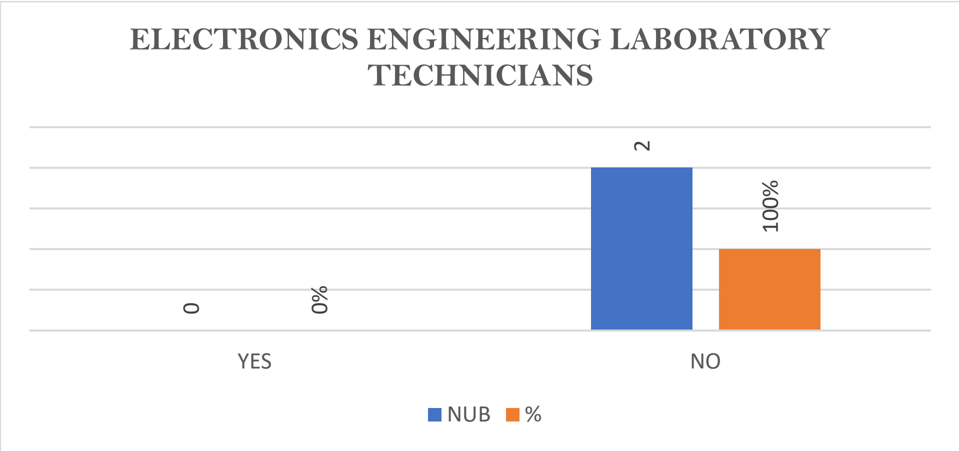


Figure 10 Analysis of laboratory technicians' responses

Figure 10 shows that the two laboratory technicians, meaning 100% of the response, indicate that troubleshooting as a skill is not foregrounded in university electronics engineering programmes. This is very significant to note as these are stakeholders that assist and guide the students during their regular laboratory experiments and practical works. What then do they foreground in their training, if troubleshooting is not accommodated in their duties to students? The next question will probe into this issue.

5.5.2 Analysis of research question 1(a)

If so, what is being foregrounded by the Laboratory Technicians? - Not applicable in this section.

5.5.3 Analysis of research question (1b)

If not, what is being foregrounded by the laboratory technicians? (if troubleshooting is not accommodated)

With respect to the responses of the laboratory technicians, the analysis on the question on what was being foregrounded in electronics engineering programme, if troubleshooting was not accommodated, pointed to the following three queries; the “what”, the “how” and the “why” as described below:

1. The “what” aspect: This refers to “What” was foregrounded in the programme;
2. The “how” aspect: this refers to how of what was foregrounded in the programme;
3. The “why” aspect: this refers to the reasons for the how of what was foregrounded in the programmes.

What was foregrounded?	How?	What informs the how?
New engineering design *“Design ability vs troubleshooting skills”*	Reading and interpreting basic circuit principles	To fit into any electronic engineering industry
	Applying scientific and enquiring mind	To be critical in identifying and solving design problems
		There is no section for troubleshooting

Table 8: Classification of laboratory technician’s responses under the “no” category

With regard to the “**what**” was foregrounded, the following category of description was elicited, namely:

New engineering design

With regard to the “**what**” aspect, this category of description was elicited, namely:

Design ability vs troubleshooting skills

With regard to this category of description, constructing new engineering design was considered as the expected outcome of the engineering profession. The two participants stressed that engineering design is integral to electronics engineering students, and that their outputs will be measured by their design ability and not by their troubleshooting skills. It was emphasized by the two participants further that there is no provision for assessing the troubleshooting skill ability of engineering students, rather, design skills are tested and assessed. Their view was underpinned by the following excerpts:

> *It is mostly design; I don’t think there is any section called troubleshooting (P05, Interview, October 24, 2016).*
>
> *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 (P04, Interview, October 24, 2016).*

For a new design, you go to the design; they should have the circuit diagram and the system diagram (P04, Interview, October 24, 2016).

With regard to the "**how**" aspect, the following two categories of description were elicited, namely:

- Reading and interpreting basic circuit principles;
- Applying scientific and enquiring mind

Reading and interpreting basic circuit principles

The two of the participants rightly pointed out that the focus of engineering design in electronics engineering programme was on having the knowledge of basic principles that serve as guides for designing in electronics. This enables them to have understanding of how circuits work, how to handle individual and group design projects. The participants had this to say:

You have to read the circuit diagram and have to use the basic principles. That's one of the major things that help you throughout (P 04, Interview, October 24, 2016);

It was validated by P05 as follows:

I think basically they read the notes and explain to you a little about troubleshooting (P05, Interview, October 24, 2016).

Applying scientific and enquiring mind

Furthermore, it was reported by one of the participants that the focus is on possessing and applying a scientific and enquiring mind to handle problems in design. An enquiry and scientific mind helps the students to evaluate and examine critically the phenomenon themselves and ask questions why they are not getting expected signals or output in a design. It helps to further identify the origin and cause of circuit malfunctioning. This is rightly presented in the excerpt highlight:

So what is expected should be what you get. And they must know what to expect, they know the theory and know how to read the diagram. If you don't know how to read the diagram, then there is a problem, and you will always have a problem with fault finding. So the main thing you have to get is individual theory of the component and how to read the diagram (P04, Interview, October 24, 2016).

With regard to the "**why**" aspect, the following two categories of description were elicited, namely:

- To fit into any electronic engineering industry;

- To identify and solve design problems.

To fit into any electronic engineering industry

One of the three participants stressed further that the electronics engineering programme emphasized engineering design not just to prepare the students for a specific industry but in order to prepare them to fit into any electronics engineering industry.

To identify and solve design problems

According to a participant, an enquiring and scientific mind is required to make electronic engineering students to identify and solve design problems (problem solving) so as to fit into any electronics engineering industry. One of the participants noted this:

> *If you don't have an enquiring mind, then you have problems. When you are looking at a circuit, you get an input, but you are not getting the correct output, then you ask yourself why. And you go back from there and see when the signal becomes no more of what is expected. As soon as it becomes what is not expected, then you classify what your fault is (P04, Interview, October 24, 2016).*

5.6 Fourth year electronics engineering students

5.6.1 Research question 1

Is troubleshooting accommodated in the university electronics engineering programme?

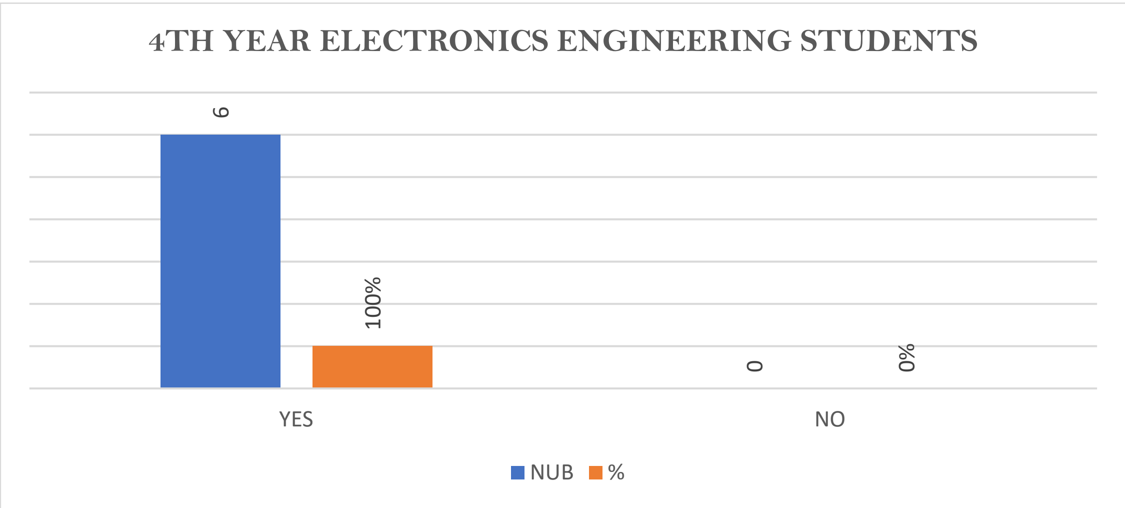


Figure 11: Analysis of fourth year electronics engineering students' responses

The outcome in figure 11 above shows that all the students, indicating 100%, confirmed that they found a troubleshooting skill component in their experiences in electronics engineering programmes. The students' responses as illustrated, are that troubleshooting was essential and embedded in their training.

5.6.2 Analysis of research question 1(a)

If so, what is being foregrounded by the Fourth Year electronics engineering students?

Further analysis revealed that the students' responses can be classified according to the context of where they experience troubleshooting practice in their training and these are categorized in the lists of descriptions as shown in Table 9 below.

With regards to the students' responses to the research question, the analysis revealed that four categories of description emerged from the participants' responses describing the categories of the context in which the participants interviewed experienced troubleshooting in their training programme.

With respect to the students' responses, the analysis pointed to the following three classification coding:

1. The "what" aspect: This refers to the "what or where" in the programme was troubleshooting embedded;
2. The "how" aspect: this refers to how troubleshooting was embedded in the programme, the focus of the description given about how troubleshooting was embedded;
3. The "why" aspect: this refers to the reasons for how troubleshooting was embedded in a particular way.

Table 9 illustrates the distributions of the categories of description as found in this section.

What was the context?	How?	What informs the how?
Troubleshooting is embedded in programming *"Troubleshooting is integral to programming"*	Solves syntax errors	It is involved in programming
Troubleshooting is complex *"The process of troubleshooting"*	Troubleshooting requires analysis	
	Troubleshooting requires times Troubleshooting requires personal effort	
Troubleshooting is embedded in design projects *"Troubleshooting is integral to design"*	Resolves design sections that malfunctions	Problem solving is part of design process
	Evaluating and testing in design	Iterative and intuitive nature of troubleshooting in design
Troubleshooting is embedded in debugging of software *"Troubleshooting is integral to debugging"*	It involves an iterative process	Intuitive nature of troubleshooting

Table 9 Analysis by categories of students' response

With regard to "what was foregrounded", the following four categories of descriptions were elicited, namely:

- Troubleshooting is embedded in programming
- Troubleshooting is complex
- Troubleshooting is embedded in design
- Troubleshooting is embedded in debugging.

Troubleshooting is embedded in programming

With regard to the "**what**" aspect, this category of description was elicited, namely:

Troubleshooting is integral to programming

Two student participants (ST01 & ST05) out of the six interviewed affirmed that troubleshooting is actually an integral part of programming. Programming is involved in the software aspects of electronics and computer engineering. As problems, errors or faults emerge in programming, the students learn to fix the problems on their own, hence they certainly engage in troubleshooting. Furthermore, when computer hardware and software break down, students write programmes to rectify the problems. This often occurs from their first year of their training through to the final year of their study. One of the students expressed further that troubleshooting is deeply involved in their training but not directly stated that it is involved, because, whenever one piece hardware fails to link up properly, they have to troubleshoot. This is illustrated in the excerpts below:

> *Basically, when I do a lot of programming as part of computer eng, (ST01, interview, October 24, 2016).*
>
> *We've been doing programming and in every programming we learn ways to troubleshoot the problem because not every programme you write is very perfect from the start (ST05, Interview, October 27, 2016).*

With regard to the "**how**" aspect, this category of description was elicited, namely:

Solves syntax errors

One of the participants stressed that troubleshooting is done when their designs experience a form of syntax error, whereby certain aspects of the hardware fail to link with each other. Syntax error occurs when there is a failure in the programming language as a result of error in the sequencing of characters written in the syntax. The programme fails to compile until all such errors are corrected. One of the participants reported this in the excerpt below:

“…… programming deals with some syntax errors which troubleshoot some problems. Like when one hardware is not linking up properly. You have to think of how to try some stuff. So you have to troubleshoot the problem. It is involved but not stated that it’s involved (ST01, interview, October 24, 2016).

With regard to the “**why**” aspect, this category of description was elicited, namely:

It is involved in programming

The participant also reiterated further that troubleshooting is embedded and experienced in programming. Programming problems have to be troubleshooted to make the faulty programmes run properly and the design function well. This was reported in the excerpt below:

“So you have to troubleshoot the problem. It is involved (in programming) but not stated that it’s involved (ST01, interview, October 24, 2016).

Troubleshooting is complex

There were two out of the six students’ participants who stressed that the complexity of troubleshooting. The participants (ST01&ST03) stressed that troubleshooting is a complex and difficult task in electronics and computer engineering programmes. With regards to their responses, three indices of difficulties were elicited namely:

- Troubleshooting requires analysis
- Troubleshooting requires time
- Troubleshooting requires personal effort.

Troubleshooting requires analysis

The response of two participants (ST01 &ST03) in this section indicated that making efforts to troubleshoot always requires thinking through and analysing the emerging problems. This shows that troubleshooting is a cognitive process of finding a way to solve the problems and always constitutes the difficulty and complexity in troubleshooting. This indication is expressed by the participants as follow:

And a lot of the time to troubleshoot could be very difficult and hard to do because you don’t know how to analyse how something could go wrong (ST03, Interview, October 26, 2016).

Troubleshooting requires time

ST03 participant's response also reflected that troubleshooting tends to take a lot of student's time. Because troubleshooting mechanism is a difficult and complex task, and students does not know how to go about solving the problems, this experience requires a lot of their time in theorizing first about the problem before addressing the problem. This view is illuminated in the excerpt below:

> *So I spent a lot of time trying to troubleshoot and debug projects. For software project, a lot of time it's debugging (ST03, Interview, October 26, 2016).*
>
> *But it took us a few night before we could figure that out (ST04, Interview, October 26, 2016).*

Troubleshooting requires personal effort

Furthermore, participant ST03 pointed out that, due to the limited knowledge they have on the practice of troubleshooting, they usually find it difficult to troubleshoot the design, having problem issues with only testing skills they were taught. The scenarios often lead to trying some personal efforts, and when this fails to work, the design process has to start from scratch all over again. Such experience is referred to as difficult and complex. This conception is revealed in the excerpts below:

> *So we've been taught things like testing and such skills and I find it a little bit hard to implement to a realistic scale. Often time there is no enough time to create the troubleshooting mechanism and so you have to make some efforts at it. So when doing troubleshooting often time I couldn't get any understanding of the problem that I am trying to solve when I am going for the troubleshooting in so much the areas of issues that are in the solutions that are coming up to a great understanding of the problem solving in the first place. And sometimes that makes me to really designing more things from the scratch after the troubleshooting (ST03, Interview, October 26, 2016).*

Troubleshooting is intuitively embedded in design

With regard to the "**what**" aspect, this category of description was elicited, namely:

Troubleshooting is integral to design

With respect to troubleshooting in design, four out of the six participants, 67% of the interviewees, foregrounded how integral troubleshooting is in electronics and computer engineering design. The four participants all stressed that, specifically in design, while they are busy with an individual and group design project, and while trying to fix problems in design, troubleshooting is often involved. Since design involve sending correct digital signals from one point to the other, soldering properly on printed circuit boards (pcb), fixing breakdown components or circuits, and testing system or circuits functionality before implementation, troubleshooting is inadvertently incorporated and embedded in the design work. Their view was illustrated in the following excerpts:

> *Specifically in design, you need to understand basically, many signals at the same time. Usually what I am used to is to send in one signal, one digital signal at one time (ST05, Interview, October 27, 2016).*
>
> *Eehm, I was busy with design project and I was building my socket on PCB and it wasn't working, my simulation which I used were correct, the codes were all correct, but it just wasn't working on my PCB (ST02, Interview, October 24, 2016).*

With regard to the "**how**" aspect, this category of description was elicited, namely:

- Resolving design sections that malfunctions
- Evaluating and systematic testing.

Resolving design sections that malfunctions

Notably, two of the participants stressed that troubleshooting is involved in order to resolve faulty and malfunctioning sections of design work. This indicates that students usually experience defects and faults in the process of designing, either the software or the hardware section and such has to be resolved to accomplish their tasks. These experiences are presented in the excerpts below:

> *So I tried different things and in the end it turned out to be the chemical used while we are soldering. I was using a different type of chemical (ST05, Interview, October 27, 2016).*
>
> *So I found that first I wasn't able to do that correctly, so what I did was that I looked at my software again and I found that if you transmit each letter with some sort of character you will be able to identify those characters with some particular deficit, so I know that this belong to that on one case (ST02, Interview, October 24, 2016).*
>
> *eah, I deal with computers a lot, like our computer breaks and actually we learn how to fix them over time, the design skill in computer engineering and software from first year…. we learn ways to troubleshoot the problem because not every programme you write is very perfect from the start (ST05, Interview, October 27, 2016).*

There was another one, it was a group project, a design project, we have to build a sort of stop watch counter without any triggering devices, this was built on bread board and it wasn't counting properly, I think it was skipping off count and also we looked for the problem and it turns out that we were missing a few resistors on the socket and once we put that, it came up. (ST04, Interview, October 26, 2016).

Evaluating and systematic testing

With respect to evaluation and systematic testing, three participants (ST03, ST05 &ST06) out of the six spoke on this theme. The participants interviewed were of the view that testing and evaluation in electronics and computer engineering is iterative and involves a lot of troubleshooting practices and processes. The three participants reported that the fact that a system, circuit or programme worked before does not guarantee that it cannot develop faults again. There is always the need to come back over and over again systematically and conduct tests to ensure all the aspect of the design works properly. This conception is established in their excerpts as presented below:

.....we learn ways to troubleshoot the problem because not every programme you write is very perfect from the start (ST05, Interview, October 27, 2016).

Everything seems to work on paper, but when we try doing it, nothing worked. So we had to test it bit by bit until we found the problem (ST06, Interview, October 27, 2016).

With regard to the "**why**" aspects, these categories of description were elicited, namely:

- Problem solving is part of design process
- Iterative and intuitive nature of troubleshooting in design.

Problem solving is part of the design process

Two of the participants noted that what informed troubleshooting in design is the process of finding solutions to all kinds of difficult problems they encounter in design which is termed problem-solving. Problem-solving has been associated with designing and this is reiterated by two of the students' participants as follows:

So I used a different kind of chemical from which I normally used and that makes it to be cleaned off and I didn't know that, and that caused my whole socket not to work properly. So as soon as I cleaned it off, it worked (ST04, Interview, October 26, 2016).

I can use the recent one through design system, everything seems to work on paper, but when we try doing it, nothing worked. So we had to test it bit by bit until we found the problem (ST06, Interview, October 27, 2016).

Intuitive nature of troubleshooting in design

One of the participants asserted that troubleshooting in electronics engineering comes by intuition. According to the student's narrative, there is no formal approach to troubleshooting in university electronics engineering education; they depend on intuitive knowledge. This is reported by the participant as stated in the excerpt below:

> *And so troubleshooting is an intuitive process, so you have to come back to everything regularly and check if you haven't broken something (ST03, Interview, October 26, 2016).*

Troubleshooting is embedded in the debugging of software

With regard to the "**what**" aspects, this category of description was elicited, namely:

Troubleshooting is integral to debugging

With regards to troubleshooting as essential element in debugging, one participant (ST03) out of the six, spoke extensively on this category. As a student who has been involved in the testing department outside the campus, a lot of time is invested in debugging, especially in the aspect of computer engineering. Debugging involves locating and correcting errors in a computer programme codes. Whenever a design refuses to work, a system fails to function or there is need to carry out tests on design, especially for software design projects, a lot of time is spent debugging. These processes involved in debugging are referred to as troubleshooting practices and captured by the participant as follow:

> *So I spent a lot of time trying to troubleshoot and debug projects. For software project, a lot of time it's debugging, debugging will cover most of the things in troubleshooting; often times also designing you can troubleshoot your design before you can implement it (ST03, Interview, October 26, 2016).*

5.7 Summary of chapter 5

The results from the analysis of research question one provide insight into the place of troubleshooting in university electronics engineering programmes. Findings from the categories under the main research question shows that, although troubleshooting does not appear explicitly in the CHE and ECSA White Paper documents and university curriculum content of electronics engineering programme, it is, however, embedded in the programmes. The lecturers and laboratory technicians noted that troubleshooting is required in the students' training in their design project and it is implicitly acquired by the students. Significantly, all the students agreed that they engaged in the practice of troubleshooting in all their electronics practical projects and circuitry laboratory works. This chapter has revealed that electronics engineering courses, laboratory practicals and assigned design projects provide an environment for troubleshooting skills. Troubleshooting ~~should~~ has a significant place in an electronics engineering programme, however, the study ~~has not~~ seek to further provide insight into how the skill is being enacted and why it is being practised in a particular way peculiar to undergraduate electronics engineering programmes. These reasons give rise to what will be considered in the next chapter.

CHAPTER 6

ANALYSIS OF RESEARCH QUESTION TWO

HOW WAS THE UNIVERSITY ELECTRONICS ENGINEERING PROGRAMME ENACTED?

6.0 Introduction

This chapter presents the analysis of research question two. To address this question, the chapter will consider the following questions.

Research question 2

2. How should or is the electronics engineering programme being enacted by:

- Policy documents - CHE and ECSA documents?
- University electronics engineering handbook?
- Lecturers - electronics engineering lecturers?
- Technicians - electronics engineering laboratory technicians?
- Students - Fourth year electronics engineering students?

The above questions are addressing the second research question of the study. The analysis will be divided into three main sections according to the list of respondents that answered the question, namely; the lecturer, sections 6.1, the technicians, 6.2 and the students, 6.3. In each of the sections, data generated will be analysed and presented accordingly.

6.1 Analysis of lecturers' responses

With respect to those that responded affirmatively, to the question *how is the electronics engineering programme being enacted?* the following three queries were used in the analysis:

1. The "what" aspect: This refers to the "categories" identified the approach of enactment in the electronics engineering programme;
2. The "how" aspect: this refers to the categories identified as how there was enactment of the electronics engineering programme;
3. The "why" aspect: this refers to the categories on what informs the enactment of the electronics engineering programme in a particular way.

Table 10 describes the analysis of responses under the category of those in the affirmative response.

What was enacted?	How?	What informs the how?
Problem based learning *"Learning by solving challenging problems"*	Breaking into the barriers of ill-defined problems	To become a proficient problem solver
Practical laboratory tasks and design *"Troubleshooting involved in design & practical tasks"*	Designing circuits on previously defined problems	Troubleshooting is involved in designing
Written examination *"Theory-based troubleshooting"*	Solving 50% content theory-based troubleshooting problems	To highlight theory problems involved in troubleshooting
Serial/Systematic check *"Systematic circuit test"*	Evaluating system modules sequentially	To highlight how troubleshooting is performed
Reinforcement *"Reinforcement learning"*	Instructing and guiding along the right direction	To learn how to troubleshoot by supervision
	Applying different design paradigms	To address each paradigm separately or combined
	Involvement in both individual and group work	To engage students in individualised, group design works.

Table 10: Analysis of how the electronics engineering programme is being enacted by the lecturers

With regard to the **"what aspect"**, five categories of description were elicited and analysed, namely:

a) Problem based learning
b) Practical laboratory tasks
c) Written examination
d) Serial/systematic check
e) Reinforcement.

Problem based learning

With regard to the "**what**" aspect, this category of description was elicited, namely

Learning by solving challenging problems

Problem based learning was emphasised by one of the participants as the means by which the electronics engineering programme is being enacted. The participant emphasised that students are given challenging problems to solve, either individually or as a group. The students then study the problem and explore possible solutions to the problem by researching. Thereafter, they formulate and test the likely best fit out of the proposed solutions and resolve any emerging problems. He further remarked that engineering problems serve as the context and the stimulus for students to learn and make personal progress in their abilities to troubleshoot. Problem based learning is self-directed in approach. It tries to mimic what the students would likely find whether in the real world or in the workplace environment. This idea was reflected by participant P01 as follow:

> *So when the students comes in, and I give them a challenging problem, and always I have to challenge them. You know the most rewarding thing for us is not necessarily the top students. The most rewarding is the student that makes mess of personal progress in his abilities (P01, Interview, October 26, 2016).*

It was also validated by another participant as presented thus;

> *So when they are designing and assembling these components on the board, then they are facing some problems and then what happens, they come to me and can also take some help from their friends (P02, Interview, October 25, 2016).*

With regard to the "**how**" aspect, this category of description was elicited, namely:

Breaking into the barriers of ill-defined problems

P01 further stressed that problem based learning focuses on breaking through the barriers of problem solving. When students are given a challenging problem to solve, they may make a mess of it at initial stage, but through a self-directed approach, as they explore through personal research, and perhaps collaboration with other colleagues and staff, they are able to break the barriers and solve the problem. It entails gathering and sharing information from others to generate possible solutions to the problem. The participant spoke further by giving an example of one of his students who was not at the top of the class academically, but after finishing his degree went for further task courses in the UK and USA and eventually became a proficient task consultant to an industry. He backed up his opinion thus in the excerpts below:

> *……he may not reach the top, but he is breaking into the barriers (P01, Interview, October 26, 2016).*

P01 gave an additional comment as follow:

> *Another good example that we have at the worse stage was from this department, he was a student of mine. He was a good student; he was not the top in the class and he*

finished. After he finished, he went out and did a task course in the UK and he went to America and did some task course and he is now the task consultant to an industry. He didn't start as that, he started in this department, he works in this office here, he worked with me and now how is it that he becomes so good. It is the problem solving approach. It is generalizable, because we are not teaching you the rules or certain theory of problem solving, we are developing within you the ability to identify problems and creatively solve it, those skills you can apply to any theory and its being applied a lot in various fields (P01, Interview, October 26, 2016).

P02 also substantiates further as thus:

Then we make some troubleshooting efforts like what is the problem? Are the components ok, is it not burnt component, is it destroyed components (P02, Interview, October 25, 2016).

With regard to the "**why**" aspect, this category of description was elicited, namely:

To become a proficient problem solver

This approach to problem solving was further stressed by P01 as the reason why the electronics engineering programme is being enacted in this unique way for electronics engineering students. It was to make them develop high level competency in electronics engineering skills, and become proficient in problem-solving. His further argued that problem based learning helps in producing future leaders who would be problem solvers. It was illuminated as seen in the excerpt below:

.....to become an intensely and efficient and effective problem solver. And we have many of them. We know this in electronics engineering, and that's why we are not throwing away this method because we know how it works. We have produced leaders out there in fields that are so diverse (P01, Interview, October 26, 2016).

Practical laboratory tasks and design

With regard to the "**what**" aspect, this category of description was elicited, namely:

Troubleshooting involved in design & laboratory tasks

One participant (P02) out of six spoke about engaging electronics engineering students with design and practical laboratory tasks as way of enacting or implementing troubleshooting in engineering programmes. According to P02, this includes assigning four science practicals in the first year, eight laboratory practical tasks in the second year, eleven in the third year, and six in the fourth year. Students are also assigned two individual and three group design projects.

He further remarked that laboratory experience in design projects gets students involved in troubleshooting skills practices. P02 stated thus:

> *Troubleshooting task is specifically by giving the students two practical in their laboratories in their third year. In second year we have four experiments and troubleshooting is involved because they design their own circuit on the breadboard (P02, Interview, October 25, 2016).*

The excerpt above is given by one of the staff participants whose information could be limited to what he engages students with alone. Further information about the practical task was obtained through enquiry from students in the course of data generation.

With regard to the "**how**" aspect, this category of description was elicited, namely:

Designing circuits on previously defined problems

The participant (P02) pointed out that student practicals are usually based on previously defined problems or tasks to run in the laboratory. Previously defined problems are specific tasks that electronics engineering students run in the laboratory yearly. The laboratory instructors already know the end results and solution to the problems. As the students run the given tasks, troubleshooting is performed on any of the section of the tasks that malfunction or did not give the required output. They engage in such design circuits on individual and group projects. As they design and construct circuits, they engage in troubleshooting in the process. This statement was made by him:

> *These are previously defined problems or task run by second year students every year (P02, Interview, October 25, 2016).*
>
> *Then we make some troubleshooting efforts like what is the problem? At that time we start from the components, we check the basic components. (P02, Interview, October 25, 2016).*

With regard to the "**why**" aspect, this category of description was elicited, namely:

Troubleshooting is involved in designing

P02 further expanded that designing circuits of previously defined problems teaches students how to troubleshoot, because not necessarily all the students make the circuit work correctly the first time or on first attempt. According to him, in electronics laboratory tasks, students usually encountered problems in putting their design together especially in their first attempt, so they will have to troubleshoot to make the circuit work as required. So he alluded to this view as follow:

> *And so troubleshooting comes up in the lab, when they are designing the circuit (P02, Interview, October 25, 2016).*

He further emphasised;

> *Not necessarily every student in the group is making their circuit correct, because every students have their different capability of understanding. So not necessarily all the students of about 130 are designing the circuit correctly in first attempt. Maybe 10 students do not understand how to connect, then they are facing some problems, then they will troubleshoot themselves (P02, Interview, October 25, 2016).*

This experience confirms the unavoidable presence of troubleshooting tasks electronics engineering students encounter and have to practise in the process of their training. Whether designing a new circuit or revising an existing faulty circuit, troubleshooting is validly present.

Written examination

With regard to the "**what**" aspect, this category of description was elicited, namely:

Theory-based troubleshooting

P02 spoke about how he addressed troubleshooting through a written examination. According to him, a larger portion, more than 50% of the problems in the examinations are troubleshooting problems. These questions are meant to help probe the students in theoretical troubleshooting knowledge. On this view, P02 has this to say:

> *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 (P02, Interview, October 25, 2016).*

With regard to the "**how**" aspect, this category of description was elicited, namely:

Solving 50% content theory-based troubleshooting problems

He (P02) further stressed that more than 50% theory questions given during examination on troubleshooting are new structures which students have never known before. Such circuit problems are given to students to solve, using their basic foundation from previous lectures. He elaborated thus:

> *In their examinations, generally I gave them suppose it is 100 marks, so 20% is very easy questions; the remaining 30% is that they will use some calculations, some formula some designing, but 50% is the tough questions which they don't know. It means they never see the circuit previously, but in the examination, they will use their own knowledge to solve those questions. So if any student solves it completely, then he is the master of that subject (P02, Interview, October 25, 2016).*

With regard to the "**why**" aspect, this category of description was elicited, namely:

To highlight theory problems involved in troubleshooting

The participant (P02) conclusively stated the reason for including troubleshooting in written examination for electronics engineering students. This is to highlight the theoretical aspects of troubleshooting in engineering programme as described below:

> *Then they will solve using the basic information which I told them during the lecture, If any student is a little bit weak in that section, so he will not be passed or if any student is not understanding anything in that basic information or that basic subject, he cannot solve that question, he will be failed and repeat that question again (P02, Interview, October 25, 2016).*

He corroborated it thus:

> *So that troubleshooting sometimes that help them solve the problem theoretically, which they can apply in their fourth year design project. Because not necessarily all the students are feeling very happy or doing very well the same way lecture (P02, Interview, October 25, 2016).*

Serial/Systematic check

With regard to the "**what**" aspect, this category of description was elicited, namely:

Systematic circuit test

P02 spoke on conducting serial and systematic checks on circuits as a form of engaging students in troubleshooting. According to him, when a fault or discrepancy occurs in the process of building up a circuit, students check the circuit serially and systematically, to identify the faults and solve the problem. At such instance, troubleshooting is assumed to be learnt by the students. He gave this view:

> *We also check all the components separately. Then they will check the modules (P02, Interview, October 25, 2016).*

With regard to the "**how**" aspect, this category of description was elicited, namely:

Evaluating system modules sequentially

Also pointed out by P02 was the idea that how the conducting of systematic checks and tests helps to learn troubleshooting is by evaluating the modules in sequence, whether they are working or not. The components are checked one after the other from one side of the module to the other and ascertaining they all function according to required specifications. His idea was underpinned by this excerpt:

….yes sir the left module is working, yes sir the middle module is working, right-hand side module is working then we have to connect again (P02, Interview, October 25, 2016).

With regard to the "**why**" aspect, this category of description was elicited, namely:

To highlight how students engage in troubleshooting

The participant further stressed that electronics engineering students were made to pass through serial troubleshooting checks so as to assist them to engage in learning troubleshooting tasks.P02 concluded with the statement in the excerpt below.

This is called troubleshooting. ... So the troubleshooting comes up as they engage in their work (P02, Interview, October 25, 2016).

Reinforcement

With regard to the "**what**" aspect, this category of description was elicited, namely:

Reinforcement Learning

Both P01 andP02 spoke about reinforcement learning style, according to them, instructors watch, observe, guide and encourage the students in the right direction and discourage in the wrong direction. They do not give them the solution, yet they guide them against going the wrong direction. The guide given serves as stimulus which strengthens or increases the probability of going the right direction and doing the right thing. Sometimes it is the students that initiate the process as they face challenging situation, they seek for consultation either among their colleagues or from the lecturers or instructors. This experience according to P01 and P02 enhances the learning of how to troubleshoot.P1 strongly unpinned the view thus:

Essentially is like throwing a child into the pool, you are not going to let the child get drowned, So is almost a reinforcement learning type of troubleshooting that we are doing (P01, Interview, October 26, 2016).

With regard to the "**how**" aspect, the following categories of description were elicited, namely:

- Instructing and guiding along the right direction;
- Applying different design paradigms;
- Involvement in both individual and group work.

Instructing and guiding along the right direction

One of the participants (P01) stressed that the work of the instructors is to instruct and guide along the right direction to follow. When students have difficulty with their project or laboratory practical, they seek for help from their instructors or colleagues and they are guided.

The instructors do not specifically teach them how to troubleshoot, but they are being reinforced and helped. He describes such assistance as shown in the excerpts below:

> *The instructor is watching, observing and guiding the child and encouraging the child if they are going in the right direction and discouraging the child if they are going in the wrong direction (P01, Interview, October 26, 2016);*

He added as follows:

> *They will take the help of demonstrators, or I will also be in the lab to help them. They may call me sir, I cannot make the correct circuit, to make the correct circuit, and then I will make the correct circuit for them after one hour of troubleshooting by the students (P02, Interview, October 26, 2016).*

Applying different design paradigms

P01 also reiterated that there are different cases of design paradigm that electronic engineering students are exposed to. These include; analogue, digital, software, and hardware design paradigms. Design comprises all these paradigms, and, as students get involved, troubleshooting is assumed to be experienced and learnt. In addition, the students are reinforced to troubleshoot when they consult their colleagues working on similar design paradigms, and consult experienced laboratory instructors and lecturers in such specific fields. P01 described the design paradigm as follow:

> *You see there are different categories or paradigms, there are different design paradigms, there is the analogue design paradigm, there is the digital design paradigm, and there is the software design paradigm. And there are paradigms where you combine these together in various proportions. So in our various design process, we put them through cases with analogue problems, digital problems, software problem (P01, Interview, October 26, 2016).*

Involvement in both individual and group work

Furthermore, P01 stressed that the lecturers reinforced the students to learn how to troubleshoot by putting them through cases of individual and group projects. According to him, exposing students to several cases of design projects helps them to encounter different scenarios of problems and how to troubleshoot such at different scales:

> *So there are various paradigms that we expose them to and the same approach is applied, where we give them the problem, they turn in their defence; they have to*

propose to us solutions and then using reinforcement approaches (P01, Interview, October 26, 2016).

With regard to the "**why**" aspect, the following categories of description were elicited, namely:

- To learn how to troubleshoot by giving support;
- To be proficient in solving problems in each paradigm separately or combined;
- To engage students in individualised discipline and interdisciplinary work.

To learn how to troubleshoot by giving support

The reason advanced by the participants (P01 &P02) for engaging students with a reinforcement learning style is to make them learn how to troubleshoot and solve problems on their own with limited support. The approach makes students to be independent in problem solving and troubleshooting. One of the participants (P01) stressed further by giving an example of a former student who graduated with BSc. Electronics Engineering. The graduate student went to the banking industry to work and eventually became a director in the bank. He was able attain such heights because he was able to solve a financial problem that others in the bank could not solve and this was attributed to the reinforcement problem solving approach he learnt from the university.

So is almost a reinforcement learning type of troubleshooting that we are doing (P01, Interview, October 26, 2016).

P01 elaborated further as follows:

I will give you an example, my best friend was a student here. He was five years behind me he did BSc in Electronics engineering, did his masters in electronic engineering as well, he went out in the industry and worked in the industry not more than one year then went into the banking industry. By the time he started he became the director of Standard Bank with no financial qualifications. I asked him how is it possible why is it possible, the reason was very simple, he was able to solve financial problems that actually they couldn't solve. That's why the directors told him, we want you to become the director. He became the business development director for all of Africa for Standard Bank. He was never taught finance, he was taught this problem solving approach (P01, Interview, October 26, 2016).

In addition to the comments above, another participant contributed further as thus:

They may call me sir, I cannot make the correct circuit, to make the correct circuit, and then I will make the correct circuit for them after one hour of troubleshooting by the students (P02, Interview, October 25, 2016)

To be proficient in solving problems in each paradigm, separately or combined

P01 expatiated further, that through the reinforcement approach, students are able to address problems in any of the design paradigms, either separately or combined, including the troubleshooting aspects of the paradigm. This will be possible because, they have been exposed to a reinforcement approach. The excerpt below reflect the view discussed.

> *So in our various design process, we put them through cases with analogue problems, digital problems, software problem (P01, Interview, October 26, 2016).*

To engage students in individualized, and group design works

According to P01, students were involved in individualised and group design aspects because they expected them to learn how to troubleshoot by reinforcement. He spoke in this regard that when electronic engineering students are supported in individual and group projects, they self-engage in individualised, discipline and interdisciplinary works which makes them proficient in their field of study and interconnect with other fields as well.

> *We also put them through certain cases which individual develop and a person will solve. We also find much in group work where as a team has to solve a problem and that is much broader in scope and so on, so we have two courses there (P01, Interview, October 26, 2016).*

6.2 Analysis of laboratory technicians' responses

The study explored the responses of participants with contrary views, on the question *how is the electronics engineering training programme being enacted?* The analysis was actualized using the following three queries; the "what", the "how" and the "why" as described below:

1. The "what" aspect: This refers to the "categories" identified the approach of enactment in the electronics engineering programme;
2. The "how" aspect: this refers to the categories identified as how the enactment of the electronics engineering programme took place;
3. The "why" aspect: this refers to the categories as to what informs the enactment of the electronics engineering programme in a particular way.

What was accounted for?	How?	What informs the how?
Competency test in engineering *"Engineering competency outcome"*	Testing students on engineering design and problem solving	There is no checklist for troubleshooting competency
Engineering tasks *"The paramountcy of engineering tasks"*	Applying scientific knowledge in engineering design and practicals	To accomplish design tasks
	Reading and interpreting and analysing the circuit	To figure out, understand problems in circuits
Systematic approach *"Understanding design as a combination of blocks"*	Breaking down systems into blocks and stages	

Table 11: Analysis of how the electronic engineering programme is being enacted

With regard to **"how"** the electronics engineering training programme is being enacted", three categories of practice were elicited and analysed, namely:

a) Competency test in engineering
b) Engineering tasks
c) System approach.

Competency test in engineering

With regard to the "**what**" aspect, the following categories of description were elicited, namely:

Engineering competency outcome

Three out of the six participants spoke about competency tests in engineering programmes. They all shared the same view that no engineering student would be tested on competency in troubleshooting, rather, what was being tested is competency in engineering design, and in problem solving. According to them, there is no specific parameter that test the troubleshooting skills outcomes of electronics engineering students, however, it is embedded in problem solving.

> *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 (P03, Interview, October 25, 2016)*

With regard to the "**how**" aspect, this category of description was elicited, namely:

Testing students on engineering design and problem solving

With respect to the how, the participant pointed out that engineering students are usually tested on how competent they are in problem solving and design project. Two participants seem to agree that electronics engineering graduates are not assessed on being competent on how to troubleshoot, and that the emphasis is always laid on how competent they are in engineering design and problem solving.

> *If that process has been tested a couple of times into the degree, automatically, troubleshooting it's been fulfilled and tested, we have people of high level competent in engineering design, competent in problem solving and embedded in that is troubleshooting (P03, Interview, October 25, 2016).*
>
> *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 comes up all the time to find why those things are not working and that comes with time (P04, Interview, October 24, 2016).*

With regard to the "**why**" aspect, this category of description was elicited, namely:

There is no checklist for troubleshooting competency

The three participants further stressed that engineering students' competency excludes the troubleshooting competency test. The curriculum does not have a place for it, neither is it represented in their handbook or laboratory manuals. The three participants insisted engineers do not have to be taught how to troubleshoot. They assumed and affirmed that the troubleshooting skill is what the students have to pick up on their own in their training as they solve problems. One of the participants expressed further the reason why electronics engineering students must not need to be specifically tested on how to troubleshoot is because they may end up in the banking industry that does not require engineering troubleshooting skills.

> *But we don't have a check box where we say competent in troubleshooting, we don't have that. I have noticed that bankers like our students, you find out our students from electronics engineering work in the banking sector, it frustrates me, and I say you are from engineering working in the banking sector. The reasons they go into banking industry is because our engineers are analytical, they can solve problems. And so to actually teach them maybe specific troubleshooting in a particular job requires teaching them troubleshooting in that particular type of job, they will pick up those skills when they get there (P03, Interview, October 25, 2016).*

P05 added as follow,

They are given a particular design and that design is having difficulty, students try to find out on their own (P05, Interview, October 25, 2016).

While P04 finally contributed thus:

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 at university level, you don't have that type of training (P04, Interview, October 24, 2016).

And,

Troubleshooting is a requirement that they pick up in their training (P04, Interview, October 24, 2016).

Engineering tasks

With regard to the "**what**" aspect, this category of description was elicited, namely:

The paramountcy of engineering tasks

Similarly, as was observed in the competency test in engineering, three participants also spoke about how paramount engineering tasks are to electronics engineering programmes. From the conception of the idea about a project, laboratory experiment or designing a system to the implementation stage, all that the engineering programme is concerned about is completing the engineering tasks of the project. Engineering tasks refers to what do engineers do or will do in their professional field of duty. Engineers are believed to work in a variety of fields whereby they analyse, develop and evaluate large-scale, complex systems. They are also believed to be the ones who design blueprints, visit systems in the field or industry and manage projects.

They bring the problems they encounter during their practical or design project. What they are all given is task to do, task as practical (P04, Interview, October 24, 2016).

The contribution was made more explicit by P05 as follows:

Students are given various projects to do, there is no one set project for any one, no specific course for troubleshooting where everybody diagnose the same or similar problems (P05, Interview, October 24, 2016).

With regard to the "**how**" aspect, the following categories of description were elicited, namely:

- Applying scientific knowledge in engineering design and practical
- Reading, interpreting, and analysing the circuit.

Applying scientific knowledge in engineering design and practicals

While explaining how engineering tasks were enacted in the electronics engineering programme, one of the participants (P04) describes it as by applying scientific knowledge in solving specific engineering problems. According to him, engineers are supposed to work in a certain way that enables them apply knowledge of theory to solve engineering tasks problems. Practical tasks are given and are expected to work in a specific way. Students are expected to know the theory and know how to interpret it in the context of the practical tasks they engage with.

> *So what is expected should be what you get. And they must know what to expect, they know the theory and know how to read the diagram. If you don't know how to read the diagram (P04, Interview, October 24, 2016).*
>
> *What is required is the theory of how things work (P04, Interview, October 24, 2016).*

Reading, interpreting and analysing the circuit

P04 also stressed that when practical tasks are given to students, through their scientific knowledge of the design, they read circuit diagrams and interpret the theories appropriately. Furthermore, the participants pointed out that engineering tasks require analysing the component parts of the design. Having the grip of the knowledge on how each of the component parts function helps the students to analyse the design appropriately.

> *So the main thing you have to get is individual theory of the component and how to read the diagram (P04, Interview, October 24, 2016).*

With regard to the "**why**" aspect, the following categories of description were elicited, namely:

- To accomplish design tasks
- To figure out, understand problems in circuits.

To accomplish design tasks

With regard to engineering tasks being enacted in the electronics engineering programme, the three participants spoke unanimously on accomplishing only design tasks as the reason for engaging students in any task in the programmes. They all specifically emphasised that no specific troubleshooting or fault-finding tasks are targeted or required. This was elicited by the participants as follow:

> *And so troubleshooting comes up in the lab, when they are designing the circuit (P05, Interview, October 24, 2016);*

P03 added succinctly:

The thing is, I just think about it, the aspect of problem solving that is the application of scientific knowledge in a specific engineering design (P03, Interview, October 25, 2016).

This was validated by P04 as follow:

They are required to be able to figure out though the knowledge of their theory, to figure out why it's not working in the design (P04, Interview, October 24, 2016).

To figure out and understand problems in circuits

One of the participants also described the reasons for engaging the students in reading and interpreting circuit diagrams and theories, as to be able to figure out and understand problems in the design tasks. They should be able to find out problems that emerge from the design on their own. While giving an explanation on the reason for analysing circuits in engineering tasks, the participant further pointed out that this is to enable the students to identify problems in the component parts of the design. Design tasks usually comprises systems and subsystems, each of these consist of components that work together to make the design function.

Then there is a problem, and you will always have a problem with fault finding. So the main thing you have to get is individual theory of the component and how to read the diagram, they are required to be able to figure out though the knowledge of their theory, to figure out why it's not working (P04, Interview, October 24, 2016).

Systematic approach

With regard to the "**what**" aspect, the following categories of description were elicited, namely:

Understanding design as a combination of blocks

One (P03) out of the six participants described what is being enacted in engineering programmes as a system approach. According to P03, a system approach involves understanding the design system as a combination of blocks and solving problems in each block one after the other. When a system is conceived as combination of blocks, each block has its function in the system to make the system work. The entire engineering project, design or task is assumed to comprise such blocks in a complex system. The degree of complexity of such system relates to the number of elements, their physical dimensions, and multiplicity of links or connections of the constituents of elements or components within the system. System approach requires understanding each blocks in the entire project, design or task, and how the blocks in the system relate to each other or interconnect with each other within the system.

All those implies the development of a solution to something from let's say block diagram within a system. It's a system approach, and it involves understanding the systems in a block and then solving the problems in each block (P03, Interview, October 25, 2016).

With regard to the "**how**" aspect, this category of description was elicited, namely:

Breaking down systems into blocks and stages

With regards to how the system approach is being enacted in electronics engineering programme, P03 pointed out that students are taught how to break down engineering systems into blocks and stages separately and solve any emerging problem. It was further emphasised that what is involved is not really troubleshooting but an attempt to figure out and solve problems.

That I suppose it's trying to solve the problem if having problems in the end, hence, not really troubleshooting (P03, Interview, October 25, 2016).

6.3 Analysis of fourth year students' responses

The student group comprises six (6) fourth year electronics engineering students. The analysis in this section will be focusing on the students' views about how troubleshooting is being enacted in the programmes.

With regards to responses on how troubleshooting skills are being enacted by fourth year electronics engineering students at UKZN, three categories of descriptions emerged. The participants' views describing how troubleshooting was enacted in the electronics engineering programme are presented in Table 12 below. The categories that emerged pointed to the following three classification coding:

1. The "what" aspect: This refers to the "categories" identified the approach of enactment in the electronics engineering programme;
2. The "how" aspect: this refers to the categories identified as to how the enactment of the electronics engineering programme took place;
3. The "why" aspect: this refers to the categories on what informs the enactment of the electronics engineering programme in a particular way.

The participants' responses according to their categories of description are described in Table 12.

What is enacted?	How?	What informs the how?
Troubleshooting strategy *"Individual troubleshooting strategy"*	Trial and error	To detect the problem space in design
	Working in modules and sections of circuit	To get correct output
Previous experience *"Previous personal experiences"*	Making reference to previous practice on problems solving	To recall informal experience
Programming problem *"Debugging is embedded in programming"*	Serially examining the system and isolating faulty components	Repair and restore faulty software/hardware links

Table 12: Analysis of how electronics engineering is being enacted by fourth year students

With regard to the **"how"** troubleshooting is being enacted, three categories of practice were elicited and analysed, namely:

- Troubleshooting strategy
- Personal experience
- Solving Programming problem
- Individual and group design projects.

Troubleshooting strategy

With respect to the "**what**" aspect, this category of description was elicited, namely:

Individual troubleshooting strategy

Three of the student participants spoke in a closely related manner on the strategies that are basically involved in troubleshooting. When the students notice that there is a malfunction with their circuit or design, or one section or the other is not working or misbehaving, they approach the problem through different means. There is no specific structure to follow, each of the interviewees gave their pattern or manner of individual approach they felt they have used at one time or the other. These pattern will be explained further in the next section on the how aspect of this category.

> *To troubleshoot the whole system you have to individually troubleshoot the software then the hardware then you troubleshoot the mechanical system to see where the source of the problem lie (ST02)*

It was confirmed by another participant as shown below:

In my project at the moment, I have gone through ideal the development process, so what I do is I will programme the module of my project and will send inputs, non-inputs and I have an expectation about output I want, and given that I will test so that I get the output that I want and then I will step through individual processes and try and see if any test run I could possibly create an extraneous value, something that is not expected (ST03)

With respect to the "**how**" aspect, the following categories of description was elicited, namely:

- Trial and error
- Working in modules and sections of circuit.

Trial and error

Three out of the six student participants spoke on using a trial and error strategy to solve troubleshooting problems in electronics engineering design or laboratory experiments. One of them explained that once the problem has been identified, the next step is to

.....try different things (meaning different attempt or means) perhaps randomly to attack the problems (ST01).

Participant ST05 equally added his voice to endorse the above statement as follows:

For hardware troubleshooting also you have to isolate each component and test each component separately to know where things are wrong. Like there was one we had faulty choke that caused the overvoltage, so we have to sought out each choke in the system to find out which one is wrong and which one is right (ST05).

Another participant among these three emphasised the trial and error strategy when responding to this question while he spoke on handling individual final year projects. This was reflected in his use of language:

"*I spent a lot of time," "I tried to step through things" and "get educated (ST03).*"

This is an indication of applying a trial and error strategy to solve troubleshooting problems. Another set of participant (ST01 & ST03) recounted their experience while engaged in group design projects which also reflected the trial and error strategy. This was reflected in their responses on attempt they made to solve a problem that emerged while they engaged in a design project that involved a stop watch which was not counting or functioning properly. It took them a few nights making certain trials before they could figure out the problem.

….you try different things of how to solve the problems. Eventually, if you can't solve the problem, you have to do it back. There is nothing that is directly related to

troubleshooting but indirectly experienced. I mean just when you have a lot of things to do, and you encounter a lot of problems. There is no specifics that teach you how to troubleshoot (ST01)

I will spend a lot of time trying to step through things and get educated (ST03).

Working in modules and sections of circuit

Two out of the six participants stressed the strategy of choosing to work in modules and sections to troubleshoot problems on their design project. The participants reported that when perhaps a trial and error strategy fails to work after several attempt, sometimes they have to result into going into the design, section by section, or check the modules one after another, troubleshooting to identify and solve the problems. It was reported by one of the participants that in a few cases, the proposed troubleshooting methods does not seem to work.

Basically, your test all the sections and see where your problem is. If its software based its basically similar, you try and figure out where about the problem came from and what you need to do to fix it. Like for example what I have with my music player, it wasn't playing very clearly, so I had a battle between my music player and my output, so I had to restore the things and makes it plays continuously and its clear (ST06)

Sometimes you just feel something is wrong and you don't know anything/a little about it you work in modules and troubleshoot that section (ST02).

With respect to the "**why**" aspect, the following categories of description were elicited, namely:

- To detect the problem space in design
- To rectify circuit malfunctioning.

To detect the problem space in design

With respect to why troubleshooting was practised in such a way, it was further explained by the students that there was nothing directly or indirectly related to how to troubleshoot in their training. However, when they have a lot of things to do, and their projects encountered a lot of problems, definitely they have to sort it out themselves. There is nothing specifically that teaches them how to troubleshoot. They have to detect the problem space themselves and solve the emerging problem.

Basically, most of the times I do research on it, you find out that most of the things you have problems with other people have the same problem, and so in the forum and *stuff you can check what they do, and you kind of apply it the way you wanted it (ST02)*

Troubleshooting is basically after you have completed a system and it's not working, you have to find out where the problem is, going through the process of debugging. You check each component to find out what's causing the problem (ST03)

To rectify circuit malfunctioning

The participants further emphasised that troubleshooting was enacted in this way because it is somehow obligatory for them to detect and rectify emerging problems so as to make their design work and to earn their degree.

So if this system stop working, I have my signals, I know what tells me that this system is ok, if this sub-system is not ok. So I just go to those signals and check. I have got a multimeter, I check each volts each point, if am reading the same voltage I ought to get then I know the problem is there (ST03).

Previous experience

With respect to the "**what**" aspect, the following categories of description were elicited, namely:

Previous personal experiences

Two of the participants significantly pointed out the use of personal experience to practise troubleshooting in the electronics engineering projects and laboratory experiments. Some referred back to their former training at the technical school or past industry experience. These previous experiences were applied once they engage with any challenging problems in analogue circuits and programming.

Well, I didn't just apply skill here, I was applying skill because, and I went to a technical school from grade 10 to grade 12. So I am a person who like working with hardware, I like designing stuff, I don't like buying and coupling, I like designing from the scratch (ST03)

It was ratified by another participant ST01 as stated below:

I learn these troubleshooting skills during practical work and work experience in industry (ST01).

With respect to the "**how**" aspect, the following categories of description was elicited, namely:

Making reference to previous practice on problem solving

Two out of the six participants stressed the personal practice on previous problems as a means of troubleshooting problems encountered in design. They referred back to a lot of bad programmes and problems they had encountered and were able to solve and applied such to troubleshoot. The past experiences inform what is expected to be done to solve the present problem situation.

> *Basically, most of the times I do research on it, you find out that most of the things you have problems with other people have the same problem, and so in the forum and stuff you can check what they do, and you kind of apply it the way you wanted it (ST05).*

Participant ST03 also added:

> *I have met a lot of problems that have been very essential and I have to troubleshoot them so that I can meet my specifications that am happy with. So through my training, I have the idea that my project should be of very good quality, I spent a lot of time troubleshooting it and trying to find the solution. So in my part, it's just a lot of experience (ST03).*

The participants further reported that, to troubleshoot, they have to remember the past problems they had solved and draw solutions from the storage. From the successful past, they draw solution for the present.

With respect to the "**why**" aspect, the following categories of description were elicited, namely:

To recall and confirm informal experience

With respect to why troubleshooting was practised through personal previous experience, the participants reported that this was an informal experience and method of solving problems of design. It was not directly taught, hence the approach available at hand was to engage in an informal method. They further testified that it was to also confirm the correctness and functionality of the past experience whether it is still valid or not. This is enumerated in the excerpts below:

> *…eehm, I was busy with design project and I was building my socket on PCB and it wasn't working, my simulation which I used were correct, the codes were all correct, but it just wasn't working on my PCB. So I tried different things and in the end it turned out to be the chemical used while we are soldering. I was using a different type of chemical. So I used a different kind of chemical for which I normally used and that*

makes it to be cleaned off and I didn't know that, and that caused my whole socket not to work properly. So as soon as I cleaned it off, it worked (ST03).

Another participant corroborated this view thus:

There was another one, it was a group project, a design project, we have to build eehm, a sort of stop watch counter without any triggering devices, this was built on bread board and it wasn't counting properly, I think it was skipping off count and also we looked for the problem and it turns out that we were missing a few resistors on the socket and once we put that, it came up. But it took us a few night before we could figure that out (ST04)

Solving programming problems

With respect to the "**what**" aspect, the following category of description was elicited, namely:

Debugging is embedded in programming

One of the participants identified an approach that is usually adopted when troubleshooting programming problems in electronics engineering. When programmes refuse to run, the student resorted to serial checking of the entire programme in other to fix the problem. This is in an attempt to isolate each section or component separately to figure out which ones are wrong and which one is right. This is highlighted in the following excerpts:

I think it depends a lot on the scenario and on what you are doing, computer engineering mostly deals with programming (TS02)

This view was supported by another participant thus:

A lot of bad programmes have led me to troubleshoot a lot in the course of my training (ST03)

With respect to the "**how**" aspect, the following categories of description was elicited, namely:

Serially examining and isolating the faulty section of the system

The interviewees stressed that once the programme does not run they have to go through the entire programme to test and identify the faulty section or part. This action can be referred to as serial examination of the programmes. For the aspect of linking up of the software to the hardware, each component is as well tested separately to know where the faults exist. This aspect was analysed by participant ST03 as follows:

What you do is, when there is a problem in programming, the programme doesn't run, so you have to go through the entire programme and test each part separately to *know where the problem is exactly to troubleshoot that problem and to fix it to move on (ST03)*

6.4 Summary

The findings from this chapter capture what is being enacted in the electronics engineering programme from the perspectives of the lecturers, laboratory technicians and fourth year students. The first section suggests that some electronics engineering lecturers recognised troubleshooting as being embedded in the teaching and learning of electronics through written examinations, design tasks and other practical laboratory courses. Some other lecturers enact electronics engineering programme basically through design tasks and reinforcement learning; they assume that troubleshooting is not formally taught in electronics engineering programmes. There is an indication that the lecturers in engineering programme do acknowledge troubleshooting in the regular tasks but it is not explicitly outlined and taught.

The second section reveals the findings from the laboratory technicians who enact the engineering training programme through a series of laboratory and design tasks. Their narratives revealed that engineering design, particularly new design tasks, is the focus. They mainly engage students in actualising design tasks and they assess, evaluate and grade them on design competency and not on their troubleshooting competency. This indicates that because troubleshooting was not recognised as one of the learning outcomes of engineering programme, it becomes the reason why it may not be given a paramount place in the programmes.

The last section, which focused on the electronics engineering students, suggests that students do engage with troubleshooting regularly in all electronics courses they undergo. It also show that they adopt individual troubleshooting strategies via trial and error since there is no structured approach. Students do adopt their previous experience from technical colleges or industry experience to practise troubleshooting. Some of the students alleged that such experiences were not adequate enough to handle effective troubleshooting problems.

CHAPTER 7

ANALYSIS OF RESEARCH QUESTION THREE AND SUMMARY OF FINDINGS

7.0 Introduction

This chapter is set to present firstly, the analysis of research question three and secondly, the summary of findings. Chapters 5 and 6 have presented the analysis of research questions 1 and 2. Analysis in this chapter is a follow up to the responses of the participants to research question 2, which focused on what informs how the electronic engineering programme is enacted. This will be followed with the summary of findings, where the relationships and interactions between the categories of descriptions from the three research questions, known as outcome spaces, are described. Hence, this chapter is divided into two main sections. Section 7.1 presents a phenomenographic analysis of research question three, while section 7.2 describes the summary of findings from the three research questions in terms of the concept of outcome spaces.

7.1 Analysis of research question three

Research question 3

3. What informs how the electronics engineering programme should or is being enacted by:

- Lecturers - electronics engineering lecturers?
- Technicians - electronics engineering laboratory technicians?
- Students - fourth year electronics engineering students?

The above questions are addressed in this section.

7.1.1 Analysis of lecturers' responses on "what informs" how the electronic engineering programme is enacted

With respect to the lecturers' responses, the analysis of the participants in response to the question on what informs what has been enacted about troubleshooting, the following three queries were used:

1. The "what" aspect: This refers to the what category of "what informs" how the electronics engineering programme was enacted;
2. The "how" aspect: this refers to the how category of "what informs" how the electronics engineering programme was enacted;

3. The “why” aspect: this refers to the why category of “what informs” how the electronics engineering programme was enacted.

In this first section, Table 13 describes the analysis of response from the first classification of participants.

“What informs”	How	The why of the “how”
The objective of engineering programme *“The objective is creativity”*	Engineering creates new products through design process	There is an art in engineering and none in science
The paraprofessional difference *“The classification of profession”*	The scope of engineering work is wide	The engineers cover so many more professional competency areas than technologists

Table 13: Analysis of lecturers’ responses (the ‘Yes’ category)

Table 13 describes the responses from the participants. With regard to “what informs” how the electronics engineering programme was enacted, the following two categories of description as reflected in Table 13 were elicited and discussed as follows, namely:

- The objective of the engineering programme
- The paraprofessional difference.

Objective of the engineering programme

With regard to the “**what**” aspect, this category of description was elicited, namely:

The objective is creativity

One of the participants (P01) interviewed spoke about the objective of engineering training programmes. According to him, the core objective of training in the electronics engineering profession is creativity. In this narrative P01 distinguished between the educational objectives of conventional engineering education and those of the science field of study, though they both depend on scientific principles. Creativity in engineering is the ability to do things in a novel way. This is assumed to be what informs why troubleshooting was being enacted in a particular way in the teaching approach used in engineering programmes.

The objective (in engineering field) is creativity, creativity is core (P01).

With regard to the “**how**” aspect, this category of description was elicited, namely:

Engineering creates new products through the design process

As pointed out by P01, scientists invent but do not create. Great inventions such as transistors, electricity and computers, to mention but a few, are invented by scientists. However, scientists are more of inventors than creators, particularly inventors of innovative engineering products. Engineers are meant to be creative and as such, they must be self-regulated. To acquire this skill, engineering students are trained to be self-regulated learners. Engineers are believed to be in the middle between the fields of creative art and science. This opinion was described in the excerpt below:

> *If I was to put it to you, my personal feeling which I can't say is necessarily broadly accepted, is that the real only major difference between science and engineering is that engineering is science with creativity (P01)*

With regard to the "**why**" aspect, this category of description was elicited, namely:

There is an art in engineering and not in science

Furthermore, P01 emphasised that there is an art in engineering but not so much in science. Engineers draw a lot of their training and skills from the creativity of art. According to him, creativity cannot be taught, that is why troubleshooting is not specifically taught in engineering. Engineers are supposed to work with strong intuition and the curriculum is designed to develop such skills. The excerpts below reflect the thought of the participant:

> *There is an art in engineering; I don't believe there is so much an art in science (P01)*

He further added to corroborate the point raised earlier;

> *......but you get engineers who made amazing things like cell phones and others and that is because, we are creative people(P01)*

The paraprofessional difference

With regard to the "**what**" aspect, this category of description was elicited, namely:

The classification of profession

Paraprofessional here refers to the classification of tasks of engineers as higher than that of technologists. Technologist are regarded as persons trained to assist professional engineers when performing complex engineering tasks.

With regard to the "**how**" aspect, this category of description was elicited, namely:

The scope of engineering work is wide

Participant P02 addressed the view that engineers have a wide scope of work to cover, their skills are directed not just towards troubleshooting skills but to so many other engineering tasks. According to the narrative, engineers work with high level complex engineering tasks, while the technologists are working at the low level. Technologists are assumed to be trained to perform better at the circuit construction level, which hones their troubleshooting skills.

People don't know, that the very first person to write a programme was a lady, she wrote the programme, yet what has scientist and physicist been able to do with transistors, nothing (P01).

Another participant underscored the point as follow:

Because what happens with the engineers is that they have so many devices, so many works, so they are not necessarily perfect (P02).

With regard to the "**why**" aspect, this category of description was elicited, namely:

The engineers cover so many professional competency areas

The reason advanced for the wide scope of engineering field is the need to deal with so many professional competency areas. There is so much to concentrate on than just one aspect as troubleshooting is not considered a generic engineering skill. According to the ECSA competency requirement, engineering consists of eleven specific outcomes. Having been expected to perform in such outcomes, engineers tend to have so many more tasks to handle than the technicians and technologists. This would not allow them to concentrate on specific tasks which technicians and technologists can handle.

7.1.2 Analysis of lecturers and laboratory technicians' responses on what informs how the electronics engineering programme is enacted (the 'No' category)

With respect to responses of participants with contrary views, the analysis of the question on what informs how the electronic engineering programme has been enacted by the lecturer and laboratory technicians (if troubleshooting was not accommodated) in engineering programme were also analysed in terms of the following three queries; the "what", the "how" and the "why" as described below:

1. The "what" aspect: This refers to the what category of "what informs" how electronics engineering programme was enacted;
2. The "how" aspect: this refers to the how category of "what informs" how the electronics engineering programme was enacted;
3. The "why" aspect: this refers to the why category of "what informs" how the electronics engineering programme was enacted.

Table 14 presents the analysis of staff according to their categories of descriptions as follows.

"What informs"	The how	The why
The curriculum specification *"Curriculum assigned Tasks"*	Compliance to changes in professional courses	Future job choice of students is unpredictable
Engineering programme's learning outcome *"Professional learning outcome"*	Based on design specification	No assessment on troubleshooting

Table 14: Analysis of the lecturer and laboratory technicians' responses (the 'no' category)

With regard to the "what informs", two categories of descriptions were elicited for this section as reflected in Table 14 above, namely:

- The curriculum specification
- Electronics engineering programme's learning outcomes.

The curriculum specification

With regard to the "**what**" aspect, this category of description was elicited, namely:

Curriculum assigned tasks

One of the participants pointed out that the task of the instructors is to engage and teach engineering students within the scope of the curricula assigned to them. The teaching material does not however include troubleshooting as content directly but embedded in it implicitly. They teach students what is within the scope of electronics engineering curriculum, what is planned in the curriculum. One of the participants reported as indicated in the excerpt below.

> *I do agree that maybe you can teach the philosophy of troubleshooting which is more of high level. Industry seems to require and teach specific troubleshooting for specific problems. I have a students that end up working in the industry for example working for Multichoice and they build test strips, so they built an equipment to test circuits. They built a circuit that essentially troubleshoot another circuit. We don't teach our students that, ok (P03).*

With regard to the "**how**" aspect, this category of description was elicited, namely:

Compliance to changes in professional courses

One of the participants explained further on the curricular content which comprises material science and the art of design in his own case. The content does not specify troubleshooting in it, but it might be indirectly embedded. He also pointed out the recent pressure from ECSA requiring engineering programme to introduce some professional courses so engineers can often end up in managerial positions. This will require engineering programmes dropping engineering courses such as quantum mechanics to be replaced with courses on professional practice and economics.

> *In actual fact, there was pressure from ECSA. ECSA require us to introduce professional courses, so engineers often end up in managerial position, so we are going to introduce courses on professional practice and economics. So we are going to drop quantum mechanics for professional courses (P03)*
>
> *…….they arrive in the workforce in a new job as someone who has acquired some broad skills, with good foundation in natural science and from a conventional university a good foundation in design (P03).*

He further added:

> *As I say from the academic point of view my main task is to get them to understand the skill of material science and in the art of how to design and embedded in that is troubleshooting (P03).*

With regard to the "**why**" aspect, this category of description was elicited, namely:

Future job choice of students is unpredictable

While responding to questions, the participant also remarked that the curricular content does not specify troubleshooting, because the choice of where to work in the future after graduating from the university depends on the students and is unpredictable. Some might end up becoming engineers in the hardware industry while others might choose to work in banks, Microsoft or or a Blackberry engineering facility. These inform the reason why they feels troubleshooting is not being taught at the undergraduate electronics engineering level.

> *I have noticed that bankers like our students, you find out our students from electronics engineering work in the banking sector, it frustrate me, and I say you are from engineering working in the banking sector. The reasons they go into banking industry is because our engineers are analytical, they can solve problems. And so to actually teach them maybe specific troubleshooting in a particular job requires teaching them troubleshooting in that particular type of job, they will pick up those skills when they get there (P03).*

Another participant further added that the matter of students' choice of practical involvement and area to specialise is an individual student's affair. The choice begins when students go for vacation work and internship in the field; during such time students make their personal choice of where to work and report back to the institution. A student may/may not develop interest in troubleshooting skills, the choice is up to them. This opinion is reflected in the excerpt below:

> *You might find out that when they go out and do their vacation works in the field, and they are meant to go and work at the field and report back what they've done (P04)*

Engineering programme's learning outcomes

With regard to the "**what**" aspect, this category of description was elicited, namely:

Professional learning outcome

One of the participants stressed that one of the reason why troubleshooting is not accommodated in electronics engineering programme is the non-inclusion of troubleshooting in the expected professional outcome of engineering students. Students are not assessed or tested on the ability to troubleshoot, in all the laboratory experiments and practical project design they offer.

> *Students are not tested on their ability to troubleshoot per se. They are judged on the outcome of the specifications they are given (P05).*

With regard to the "**how**" aspect, this category of description was elicited, namely:

Based on design specification

The participant pointed out that the students are expected to be assessed on the final outcome of design specifications given them. They watch, observe and score the students based on whether they are able to realise the design or not and not the process of problems encountered and how they solve the problems. The details about a specific design process and product are given and, once such requirements are met, the individual student or group of students are assessed. The specification may include drawings, dimensions, functionality, optimal performance and so on. It is not about troubleshooting; it's all about getting the desired design result. The participant briefly describes this in the excerpt below:

> *So if the circuit works, it means the students pass the design. We are not there to judge them on troubleshooting, we are there to watch them, to observe if they not getting a particular signal at certain point. To watch them and see if they probably get the end result (P05).*

With regard to the "**why**" aspect, this category of description was elicited, namely:

No assessment on troubleshooting

With respect to the reason why the engineering programme learning outcomes did not include troubleshooting, the interviewee reported that it was not required for their certification. Certifications are given based on the students' ability to achieve a working design.

The reasons they go into banking industry is because our engineers are analytical, they can solve problems. And so to actually teach them maybe specific troubleshooting in a particular job requires teaching them troubleshooting in that particular type of job, they will pick up those skills when they get there (P03)

Another participant added;

We are not there to watch them troubleshooting. See end result (of design) and give them certification (P05).

The participants here observed that there is no specific assessment strategy for engineering students on troubleshooting unlike other tasks which are formally assessed with a checklist. Engineering students are assessed on tasks they believed are of high significance to the profession, such as competency in problem solving, competency in complex engineering design, competency in professional practice and so on.

7.1.3 Analysis of students' responses on what informs how the electronics engineering programme is enacted

With respect to the students' responses, the analysis of the participants' responses to the question on what informs what has been enacted about troubleshooting in electronics engineering education programme, the following three queries were used:

1. The "what" aspect: This refers to the what category of "what informs" how electronics engineering programme was enacted;
2. The "how" aspect: this refers to the how category of "what informs" how the electronics engineering programme was enacted;
3. The "why" aspect: this refers to the why category of what informs" how the electronics engineering programme was enacted.

Table 15 presents the analysis of students' response according to their categories of descriptions as follows.

What informs?	How?	The why of how?
Troubleshooting is personal *"It is accomplished through personal efforts"*	Creates solution individually	No one teaches troubleshooting at the university
Intuition and research *"Troubleshooting is intuitive in nature"*	Applying different approach	To detect the right approach
Troubleshooting requires experiential knowledge *"Drawing from case-libraries of past experience"*	Recalling past experience	To apply the best solution path

Table 15: Analysis of students' responses

With regard to what informs "what was enacted", the following two categories of description were elicited, namely:

- Troubleshooting is personal
- Intuition and research
- Troubleshooting requires experiential knowledge.

Troubleshooting is personal

With regard to the "**what**" aspect, this category of description was elicited, namely:

It is accomplished through personal efforts

One of the participants in the focused group asserted troubleshooting is a personal skill. Most of the students interviewed in the focused group agreed that their experience of troubleshooting is personal. This is why they apply individual strategies such as trial and error and other unstructured strategies they come across. Trial and error, split-half, functional discrepancies, exhaustive and topographic strategies are possible strategies novices in troubleshooting usually adopt since they are not aware of any structured approach. Some of the participants gave their reason for enacting troubleshooting skills in that way as described below:

> *Well in terms of troubleshooting I guess all of us can agree that it's personal (ST05)*

The participant further emphasised:

> *......because there are so many aspects you can deal with and there are different ways to develop, and there are different ways of troubleshooting (ST05)*

With regard to the "**how**" aspect, this category of description was elicited, namely:

Creates solution individually

The participants revealed that they create solutions on their own to troubleshooting problems they each encounter. They were not taught and no one will teach them, so the best option is to create solutions by themselves to the problem that emerges. They learn to be creative by using their imagination individually. This was further explained in the excerpts below:

> *....so you know that because you design the system yourself, you know the possible areas of your design, you know this is how I think and this is the final end and this is what may be the problem, this is what I have not gotten (ST05)*

Another participant validated the idea as stated below:

> *Because I want to solve the problem, basically when you want to solve a problem you have to find out what the problem is, then you find out reasons why they evolve and then you find out the best way to solve the problems and apply it (ST02)*

With regard to the "**why**" aspect, this category of description was elicited, namely:

No one teaches you how to troubleshoot at the university

The participants stressed that what informed the steps they took was the need to solve the problem and that demands applying different methods until the actual fault(s) is identified and the problem is addressed and solved, because no one teaches you how to do this. Individual strategies become the practice of fourth year electronics engineering students. Sometimes you are under pressure to accomplish a design task, so you have to find a way out to troubleshoot emerging problems on the design task. This was underpinned in the excerpts below:

> *....when you are at varsity, they don't really train you how to create problems, the problems are already there then they train you how to create solutions and how to come up with cost-effective solutions. So basically what needed to be done, the problem must first be identified, so I had to know what needed to be done to solve that problem (ST03)*

He added further:

> *I think the other reason which might have helped me is pressure, because you know that you have to get this thing to work (ST03).*

Another participant stated as follows:

> *Because there are so many aspects you can deal with and there are different ways to develop, and there are different ways of troubleshooting (ST05)*

Intuition and research

With regard to the "**what**" aspect, this category of description was elicited, namely:

Troubleshooting is intuitive in nature

In the focus group, electronics engineering students also identified intuition as the reason why they enact troubleshooting in a particular way peculiar to them. The students stressed that they depend on their intuition to solve both hardware and software electronics troubleshooting problems. It was recognized as one of the main approach to engage in troubleshooting of any kind. This was revealed in the excerpt below:

> *Troubleshooting is not something that you can go to a class and say this is how you troubleshoot. It's not, it's mostly from intuition and experience most of the time. But there could be a way like for example if you have electrical system or let's say you have an electronics system, you have to break up the system into components, like for example you have the power supply or software control circuitry or hardware control circuitry, so in the power supply if something is not working in terms of power, it means something is not being powered, then you see how it's working then you work your way up the system like that (ST04).*

With regard to the "**how**" aspect, this category of description was elicited, namely:

Applying different approaches

Intuition comes to play when there is a problem to solve and there is no defined solution path. Electronics engineering students depend on this by researching into what others had done; they apply what their intuition directs them to practise. After researching, they try different approaches in an unstructured way to solve the problem. It was reported by one of the participants in the excerpt below:

> *I knew in my head what I want everything to be, when I made my specification with my supervisor, so I made it and I research it out individually, and I saw the different approaches that other people have taken and different approaches others have put off. And from those I decided which is the best and the most approaches that is likely to be successful (ST01).*
>
> *And then when I tried something out and it didn't work, then I have to go back and reassess and find other solutions and implement those until they are successful (ST01)*

With regard to the "**why**" aspect, this category of description was elicited, namely:

To detect the right approach

The different approaches are tried until the right and proper solution is discovered and applied. The participant presented what informs the application of different approach as stated below.

And from those I decided which is the best and the most approaches that is likely to be successful (ST01).

Troubleshooting requires experiential knowledge

With regard to the "**what**" aspect, this category of description was elicited, namely:

Drawing from case-libraries of past experience

The students revealed that troubleshooting comes from remembering past experiences on a type of problem that was once solved. Individual students seem to develop a case-library of solution to past problems they had once encountered. They can extract from this library cognitively to apply to current similar situation. This is the case with the electronics engineering students as they gave as their reasons in the excerpts below:

> *But it's not something you actually learn as a trade. It's something you learn through experience (ST02)*
>
> *Well, I didn't just apply skill here, I was applying skill because I went to a technical school from grade 10 to grade 12. So I am a person who like working with hardware (ST05)*

Another participant added:

> *.....most of the times or for you to be efficient enough as possible in terms of troubleshooting, you need to be exposed to a wide variety or combination of different problems, you see the problems might be different all the time so you may never know what problem you need to troubleshoot (ST04).*

With regard to the "**how**" aspect, this category of description was elicited, namely:

Recalling past experiences

The students observed that how they troubleshoot is mostly dependent on the ability to recall past experiences. They were able to do this due to one or two reasons such as, remembering their high school, technical college or industry experience of how certain troubleshooting process was done with success. This was underpinned in the excerpt below:

> *I do learn this experience during practical work and work experience at the company (ST04)*
>
> *If you have a problem, depending on your application, on how you expect it to work, you understand the problem first by comparing what you expect to what is happening, so obviously you have the background knowledge of everything you obtain so*

depending on what happened and what's not happening, you compare the two and you think of what could be the possible problem (ST05)

With regard to the "**why**" aspect, this category of description was elicited, namely:

To apply the best solution path

The participants further stressed that they draw from past successful experience in order to determine and apply the best solution path to solve the problem.

"....then you go about addressing each problem step by step to see whether that problem is what is causing your output to be not as you expect it to be (ST05).

Also corroborated by another participant as stated below;

And from those I decided which is the best and the most approaches that is likely to be successful (ST01).

7.2 Summary of findings

Figure 12 presents the summary of findings of analysis of the results from the all the participants.

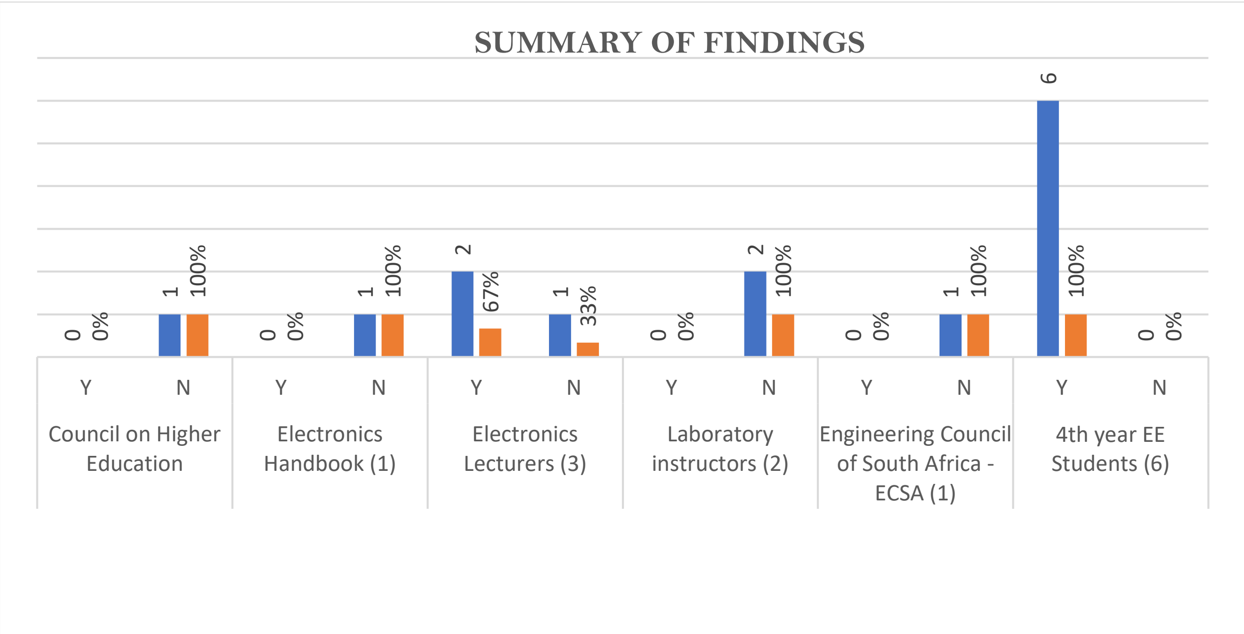


Figure 12: Summary of findings of analysis

Figure 12 illustrates the summary of findings on the analysis of the three research questions in the study. It worth noting that at the initial stage of asking the question whether troubleshooting is accommodated in electronics engineering programme, the participants differed in their opinion and narratives. However, while foregrounding their responses, findings indicated that they converge in what they practise and what informs what they practise.

As shown from Figure 12, findings indicates that the following provided evidence that troubleshooting was not accommodated in electronics engineering programme; the CHE document, ECSA document, university electronics engineering handbook, and the two laboratory instructors' participants were found in the same category, indicating a 100% response. Two out of the three lecturers interviewed indicating, 67%, had different views and affirmed that troubleshooting was accommodated, while one other lecturer indicating 33% did not affirm the accommodation of troubleshooting in electronics engineering programmes. Significantly, all the six students that participated in the interview, indicating 100%, affirmed that troubleshooting was embedded in various aspects of their experience from first year to fourth year.

The categories of description from the three research questions are organized hierarchically and grouped based on their similarities and differences to find the outcome spaces as reflected Appendix C. The outcome spaces describe the end results of analysis of the three research questions as discussed below.

7.2.1 Outcome spaces of data on what was foregrounded on troubleshooting in university electronics engineering program

On research question 1a, the following were realised as outcomes to participant's responses.

1. The approach
2. Curriculum delivery
3. Troubleshooting in design.

The Approach

The participants in this category narrated that the approach in the undergraduate electronics engineering programme is unique to engineering education. The lecturers characterised the approach as that which instils creativity to the students and makes them analytical when solving complex engineering problems in industry. The students also corroborated this as they confirmed the intuitive nature of troubleshooting. They foregrounded this as their experience in troubleshooting, though they were not taught the direct formal approach to troubleshoot, but they apply their intuition when problems or faults occur in various aspects of their training. The approach addressed in engineering education conveys the implicit nature of the pedagogy of teaching and learning in this programme. The findings revealed that teaching to think in this electronics engineering programme does not address either explicit instruction about troubleshooting, nor the cognitive apprenticeship paradigm. Rather the students are regularly taught through a series of problem-solving design tasks.

Curriculum delivery

The participants in this category also pointed to curriculum delivery in undergraduate electronics engineering as part of what is foregrounded. While the lecturers emphasised the time spent on engaging the students to cover the curriculum, the students confirmed what is foregrounded in the curriculum is design from first year to their fourth year of study. The lecturers structure the time from first year to final year to complete different projects before graduating the students. Ability to design is at the focus of what is foregrounded within the timeframe.

Troubleshooting in design

The participants also spoke on the context of what is foregrounded in undergraduate electronics engineering programmes. The lecturers foregrounded design as the focus of problem solving; they assumed troubleshooting is inherently embedded and focused on the ability to identify various design problems while the students foregrounded focussing on the context of troubleshooting embedded in design, project testing and evaluation, programming and debugging of software. The two groups of participants in this category both expressed that design is the place where troubleshooting is foregrounded in the electronics engineering programme. While it may not be explicitly written in the curriculum, it is there in practice.

7.2.2 Outcome spaces of what was foregrounded in the university electronics engineering programme if troubleshooting is not accommodated

On research question 1b, the following were realised as outcomes of analysed data from documents and participant's responses.

1. Solving complex engineering problems
2. Design
3. Organic troubleshooting.

Solving complex engineering problems

This section comprises the CHE document, ECSA document, University electronics engineering handbook and laboratory technicians' responses. Noticeably, all the results analysed emphasised this outcome as significant to undergraduate electronics engineering education programmes. It indicates that graduates are prepared to acquire enough competence and ability to engage in solving complex engineering problems. Solving complex engineering problems is perceived as one of the pivots of real professional practice in an electronics engineering career.

Design

Design, in the context of electronics engineering in the university, is problem based, which implies students often make mistakes or have errors in their circuit designs and need to revise their circuits through a troubleshooting process. Design is another common ground of thought in this section. It is significantly foregrounded by all. It was noticed in one of the responses specifically that the scope of engineering jobs stops at design. This indicates the high premium design carries in electronics engineering programmes. This includes applying a scientific and enquiring mind to solve complex engineering problems, performing procedural and non-procedural design, identifying, analysing and solving complex engineering problems, engaging in practical design process and products regularly. All this activities are believed to be commonly planned and proposed for electronics engineering programmes.

Organic troubleshooting

In the same vein as design is the concept of organic troubleshooting. This is being foregrounded as a top-down problem-solving approach. Organic troubleshooting is foregrounded in place of structured troubleshooting process. Since there was no provision for a formal troubleshooting process, students work their way through learning to troubleshoot, they naturally pick up the skill on their own. Organic troubleshooting is not a structured pre-planned troubleshooting approach but an attempt to remove supposed problems that obstruct the process and product of design.

7.2.3 Outcome spaces of how the electronics engineering programme was enacted in the university

On research question 2, the following themes, equivalent to the outcome spaces, were developed from the analysis of the participant responses.

1. Individual-based practice
2. Theory-based practice
3. Design-based practice.

Individual-based practice

Findings revealed that the undergraduate electronics engineering programme is being enacted through a series of individual-based practices. This is achieved through individual laboratory practicals and projects. Lecturers engage electronics engineering students in individual projects and are given support in situations where they are in need. Findings also show that students apply individual strategies such as trial and error to solve troubleshooting problems. In the electronics engineering programme, no one teaches a direct or formal troubleshooting approach; neither the lecturers nor the laboratory instructors interact and teach formal troubleshooting to a student or group of students. There is no form of apprenticeship training on troubleshooting or other skill practices. This series of individual practices are not consistent with the cognitive apprenticeship whereby an expert troubleshooter interacts and engages with a student or group of students and instructs how to troubleshoot or solve problems. In apprenticeship training style, the instructors address specific troubleshooting tips before the tasks begin and highlight common pitfalls relevant to particular laboratory activities. Findings show that this is not the case with undergraduates engineering education programmes.

Theory-based practice

Findings show that one of the means of enacting undergraduate electronics engineering programme is via written examination. This indicates a theory-based practice. Students are engaged in solving troubleshooting problems theoretically with the aim of reinforcing them to apply the learnings to design problem solving. It is assumed that written examinations will help students learn how to troubleshoot. This is seen and observed to be underpinned by the written examination and application of scientific theories to solve design problems.

Design-based practice

Findings from this study revealed that most undergraduates' electronics engineering practice is being enacted via design-based practice. From the courses in the curriculum, the pedagogy of teaching and learning by the lecturers and laboratory instructors to the students' regular practices, all are pointing towards design-based practice. For instance, the handbook emphasises individual and group electronics design projects, lecturers emphasised problem-based learning, serial/systematic testing, practical laboratory tasks, a variety of engineering tasks; all these were to be found in the design process and products; and the laboratory instructors emphasised engineering tasks in laboratory and design projects. The students equally added their experience of solving programming problems in design.

7.2.4 Outcome spaces of what informs how the electronic engineering programme was enacted in the university

On research question 3, the following themes, equivalent to the outcome spaces, were developed from the analysis of the participant responses.

1. Engineering programme learning outcome - design based
2. Engineering programme curriculum - individual, theory and design-based.

Electronics engineering programme learning outcomes

Findings from the analysis of the results of what informs how the electronics engineering programme was enacted at university revealed that the engineering programme is largely dependent on the planned learning outcomes. This was underpinned by the observed actual outcomes of how electronics engineering programme was enacted which included; emphasis on creativity in engineering, analytical and problem solving ability, meeting design specifications and students application of scientific knowledge to solve complex design problems. These were all qualitatively described in two distinct ways as the objectives of the engineering programme and the actual engineering programme's learning outcome. These two outcomes were described and originated from the two documents analysed in the study; particularly, the CHE and ECSA documents.

Engineering programme curriculum

Findings further revealed that two qualitatively distinct categories is seen to describe what informs how electronics engineering programme is being enacted in the university in the context of the programme curriculum. These include; the paraprofessional difference between engineers and technologists in industry and the curriculum specifications given for implementation in the institutions. Findings showed that the curriculum is design-based and also theory-based. The lecturers and technicians are guided by changes in the discipline curriculum as directives are being given by the policy makers and accreditation agents. Another major finding is the wide scope of competency areas required to be enacted by the programme, which is meant to prepare the graduates for enough space to make choice of specialised areas in electronics engineering. This distinguishes engineers from other paraprofessional experts such as technologists and technicians.

7.3 Summary of Chapter 7

This chapter presented the analysis of research question 3. Two main categories of description emerged from the analysis of data from lecturers and laboratory technicians. The students' response produced three categories of description. These were the critical dimensions of what lecturers, laboratory instructors and students conceive as informing how the electronic engineering programme was being enacted in the university. The intended factors were described by the participants in relation to troubleshooting skills in the electronics engineering programme. The categories of description were later synthesized into themes that represent the outcome space, the results of findings in the study which was presented in the last section of the chapter. The summary of findings from the analysis of the three research questions serves as the basis for discussion to locate the place of troubleshooting in the undergraduate electronics engineering education programme. The next chapter presents the discussion by using Lefebvre's theory of place and space to locate the place of troubleshooting in the undergraduate's electronics engineering education programme.

CHAPTER 8

DISCUSSION

EXPLORING THE PLACE OF TROUBLESHOOTING IN A UNIVERSITY ELECTRONICS ENGINEERING PROGRAMME

8.0 Introduction

This chapter attempts to situate the place of troubleshooting in university electronics engineering programme within the three spaces of Lefebvre's spatial triad for the purpose of discussion of the implications beyond the presentation and findings of results. As observed by Lefebvre, the divisions between the conceived, the perceived and lived spaces are not considered rigid, but fluid in nature; that implies there are internal interactions amongst the triad. The spaces within the triad intersect and interrelate with each other as shown in Figure 13.

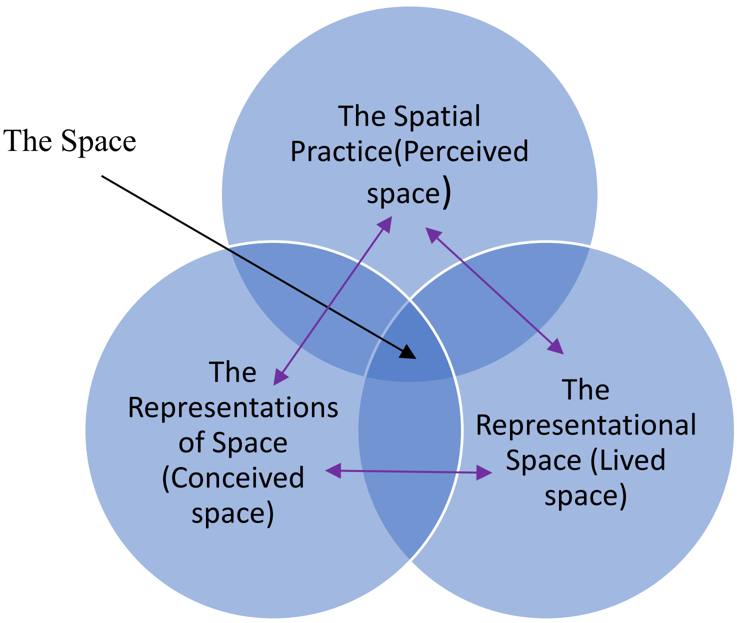


Figure 13 Lefebvre's theoretical model applied in this study

As Lefebvre also noted, there is a danger of introducing divisions and defeating the objectives of applying the theory, which is to discover the unity of the produced space in the process of production (Lefebvre, 2012). Hence, the perceived, the conceived, and the lived spaces overlap with the corresponding notions of spatial practice, representation of space, and the representational spaces. As earlier stated in chapter 3 of this study, the three notions of space that were used to underpin Lefebvre's theory in the light of this study are:

(i) ***The conceived space*** which is the representations of space; this represents the CHE document on qualification standard for electronics engineering programme and ECSA document on accreditation standard for electronics engineering programmes;

(ii) ***The perceived space*** which is the spatial practice; this represents the institutional perception via the university electronics engineering curriculum, the lecturers and the laboratory technicians and

(iii) ***The lived space*** which is equally known as the representational space; this represents the electronics engineering students' lived experiences in the institution.

These three notions will be treated as they internally relate to the system as a whole in exploring the place of troubleshooting in university undergraduate electronics engineering programmes. The framework is flexible enough to allow one to enter the triad at any moment and theorise from that point. However, for the purpose of this study, the discussion will start from the conceived space, to the perceived and finally the lived space. Space is the primary subject in Lefebvre's theory. In this study, the place of troubleshooting in undergraduate electronics engineering programme is the primary focus of critique. Thus, the chapter would consider three main sections, sections 8.1, 8.2 and 8.3. Each section will address discussions on each of the spaces of Lefebvre's triad in the production of space.

8.1 Troubleshooting in the conceived space of a university electronics engineering programme

This section discusses the space constructed by the professionals and technocrats, the space of the state and capitalist society, in the case of this study, it is the CHE and ECSA. In Merrifield's words:

> *It is the space constructed by assorted professionals and technocrats, ...it includes planners and engineers, developers and architects, urbanists and geographers and others of scientific and bureaucratic bent;....it implies the world of abstraction, what's in the head rather than in the body, it's a dominant space of any society, "intimately tied to relations of production and to the 'order' those relations impose, and hence to knowledge, to signs, to codes, to frontal relations.....It's the space of the state, the capital and bourgeoisie* (Merrifield, 2006, p. 109 – emphasis mine).

The conceived space is the most influential among the three categories in the production of space. As always, the case with Lefebvre's interpretation, the conceived space is associated with control of other spaces in the triad. The control is exercised by influencing the social relationships of the perceived and the lived spaces in the triad. This is reflected in the findings from this study. In the present study, CHE and ECSA are responsible for producing the government White Paper policy and standards that guide and inform the university electronics engineering programmes. Lefebvre sees the production of academic knowledge as being identified and provided by the ruling class; (Lefebvre, 1991; Middleton, 2017). In line with Lefebvre's critique of the educational process in the production of educational spaces as part of his contention, he laid emphasis on pedagogical concepts in universities and schools (Lefebvre, 1991). Lefebvre asserted that the everyday life of educational process is influenced by its pedagogy, hence its production requires critique (Lefebvre, 2009). Middleton (2017) describes pedagogy as any practice or principle, process or experience that affects learning. It is a form of unifying concept around which fragmented disciplines and fields of education studies, which Lefebvre contested against, cohere (ibid. p. 4). Relevant to this study, among the concepts Lefebvre raised concerns about are the pedagogies of alienation and appropriation, which have to do with theory and practice in educational process. The conceived space in this study produced the discoveries highlighted in the sub-section below.

8.1.1 Pedagogical alienation and appropriation by CHE and ECSA

On the place of troubleshooting in this undergraduate electronics engineering programme, pedagogical alienation, as asserted by Lefebvre, takes certain academic knowledge for granted as the property of the ruling class, which is the institutional administrators. From the result of this study, the ruling class, otherwise known as the government professionals and policy makers via CHE, and the ECSA authority on electronics engineering programme detached troubleshooting from being an essential part of the competency skills and engineering programme's learning outcome. The CHE and ECSA provide the standards and requirements in the conceived space for undergraduate electronics engineering programmes. The policy documents from this duo in the conceived space place significant emphasis on generic engineering competencies such as design and solving the complex engineering problems. The CHE document on qualification standards for Bachelor of Science in Engineering and Bachelor of Engineering comprises eleven skills and applied competency skills and four major levels of knowledge to be demonstrated, which are transformed into eleven exit level outcomes from ECSA for electronics engineering programme, as shown in Table 16:

Skills required for graduates	Knowledge required to demonstrate
Ability to identify, formulate, analyse and solve complex engineering problems creatively and innovatively.	A systematic, theory-based understanding of the natural sciences applicable to the discipline
Ability to apply knowledge of maths, natural sciences, engineering fundamentals and engineering speciality to solve complex engineering problems.	Conceptually-based mathematics, numerical analysis, statistics and formal aspects of computer and information science to support analysis and modelling applicable to the discipline
Ability to perform creative, procedural and non-procedural design and synthesis of components, systems, engineering works, products or processes.	A systematic, theory-based formulation of engineering fundamentals required in the engineering discipline
Ability to demonstrate competence to design and conduct investigations and experiments.	Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline
Ability to demonstrate competence to use appropriate engineering methods, skills and tools, including those based on Information Technology.	
Ability to demonstrate competence to communicate effectively, both orally and in writing, with engineering audiences and the community at large.	
Ability to demonstrate critical awareness of the sustainability and impact of engineering activity on the social, industrial and physical environment	
Ability to demonstrate competence to work effectively as an individual, in teams and in multidisciplinary environments.	
Ability to demonstrate competence to engage in independent learning through well-developed learning skills.	
Ability to demonstrate critical awareness of the need to act professionally and ethically and to exercise judgement and take responsibility within own limits of competence.	
Demonstration of knowledge and understanding of engineering management principles and economic decision-making.	

Source: Qualification Standard for Bachelor of Engineering (CHE, 2015)

Table 16: Skills and knowledge required for the electronics engineering programme

These eleven competency areas are rated highly and are significant for all electronics engineering undergraduates. These competency skills and required level of knowledge are being produced and reproduced in the other two spaces of the triads, namely, the perceived and the lived space. On the other hand, pedagogical appropriation is the way of adapting to the theory of teaching and learning provided by the conceived space. It occurs in educational spaces when there is a discordance in standards, an abnormality in the lived space as a result of the codified knowledge prescribed by the professionals, the administrative division of the institution (Middleton, 2017, p. 5; Lefebvre, 2012, p. 205). This scenario was discovered in this study as the policy documents interacts with the perceived and lived spaces on the context of the place of troubleshooting in undergraduate electronics engineering programmes. While the space of the electronics engineering programme policy interacted with the other two spaces, a difference in emphasis on what was foregrounded about troubleshooting was observed. As the skill of troubleshooting was not explicitly outlined in the policy statements and standards, this differs from what was foregrounded in the perceived space of the lecturers and laboratory technicians, and the lived space of fourth year electronics engineering students, concerning troubleshooting in electronics engineering programmes. The policy documents was more focused and explicit on design ability and foregrounded eleven attributes an engineer must demonstrate as skills and applied competency.

8.2 Troubleshooting in the perceived space of the university electronics engineering programme

The perceived space is the physical space, also known as the spatial practice, the common sense belief which is characterized by adaptation to the principles of the conceived space (Lefebvre, 2012, p 38). It is a space of how thought becomes real action, a link between the conceived space and the lived space. In Lefebvre's production of spaces, the spatial practice embodies a close association between daily realities and urban reality (Lefebvre, 2012). The perceived space is informed by the abstract space. The abstract space is being transformed and perceived in the spatial practice. In Lefebvre and Soja's interpretations, this space is the second space that aims at a formal science of space (Soja, 1989). The perceived space conveys ideas within the spaces in a concealed manner and makes it suitable and adaptable to other spaces in a dialectical interaction. It mediates between the conceived and the lived space. The perceived space is in-between the abstract space of the state (the government institutions) and the everyday lived experiences. The role of the perceived space in the production of space in any institution of social space is to perceive the world in a common sense manner and pass it on. Merrifield articulates it thus:

> *"Spatial practices are spaces that have close affinities with perceived space, to people's perceptions of the world, of their world particularly its everyday ordinariness. ... it structures lived reality, include routes and networks, patterns and interactions that connect places and people – it aids or deter sense of location and the manner in which a person acts". (Merrifield, 2006, p. 110).*

The perceived space of this study comprises the outcomes of findings from the university electronics engineering discipline curriculum, the electronics engineering lecturers and laboratory technicians. These outcomes are discussed in the context of the place of troubleshooting in undergraduate electronics engineering programmes. This space constitutes a larger portion of the process of production in university electronics engineering programmes, and interacts largely in a dialectical manner with the conceived space of the CHE and ECSA, and the lived space of fourth year electronics engineering students.

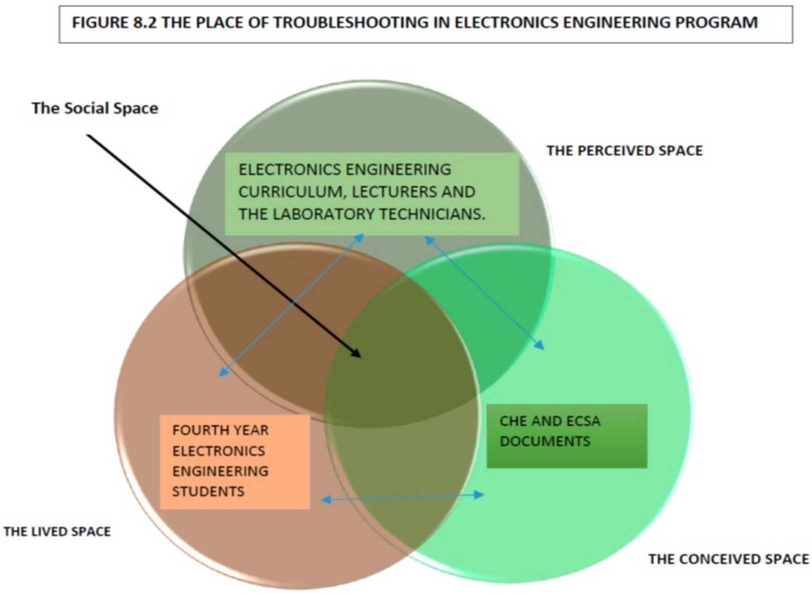


Figure 14: The relationship of the perceived space to other spaces in the triads

The habitual spatial practices in the university electronics engineering programme includes regular teaching and learning of the curriculum, applying the aim and objectives of the curriculum, the content and procedures, applying scientific knowledge to engineering practices in laboratory practicals and giving individual and group projects to student (CHE, 2015; ECSA, 2017). This space of the institution mediates between the administrative "order" of CHE and ECSA, and the electronics engineering students. Lefebvre (2012) asserted that since around 1910, "a certain space was shattered" – the space of common sense. Since then, according to Lefebvre, "the space of common sense, of knowledge, of social practice, of political power was modified; and another space thitherto was enshrined in everyday discourse, a space of the abstract thought - this was a crucial moment and such were the shocks and onslaughts suffered by this space today that it retains but a feeble pedagogical reality, within a conservative educational system" (ibid. p. 25).This is a change in the education system that was assumed has impacted on the educational system to date. Lefebvre (2012) and Middleton (2017) noticed this kind of change in academic disciplines and such has been found to reflect in the perceived space of this study. The curriculum fragmented electronics engineering programme learning areas and isolated troubleshooting from it, however, the lecturers attested to the fact that troubleshooting is implicitly attached theoretically to the programmes. The results of the study showed that, informally, troubleshooting is in the regular laboratory practical, in design projects and also in the approach to teaching and learning, yet the policy from CHE and ECSA does not accord much to significance to it as other skills. The university electronics engineering curriculum was not categorical in its inclusion in content and practice. This is an indication of not regarding troubleshooting as important as other skills in an electronics engineering career. The perceived space in this study produced the discoveries highlighted in the sub-sections below.

8.2.1 The significance of troubleshooting in the perceived space of an electronics engineering programme

Studies have shown that engineering programmes do not always consider troubleshooting an important skill in the programme activities, probably because much emphasis has been laid on general problem solving skills, systematic design skills, analytical skills, critical thinking and the ability to apply scientific knowledge to solve complex engineering problems (Passow,2012; Trevelyan, 2007; Brumm, Guardiola, Hanneman & Mickelson, 2001). Despite the fact that troubleshooting has been categorized as one of the problems largely associated with engineers (Jonassen, 2010, 2011), most of the participants in this space did not attach significance to it in electronics engineering programmes.

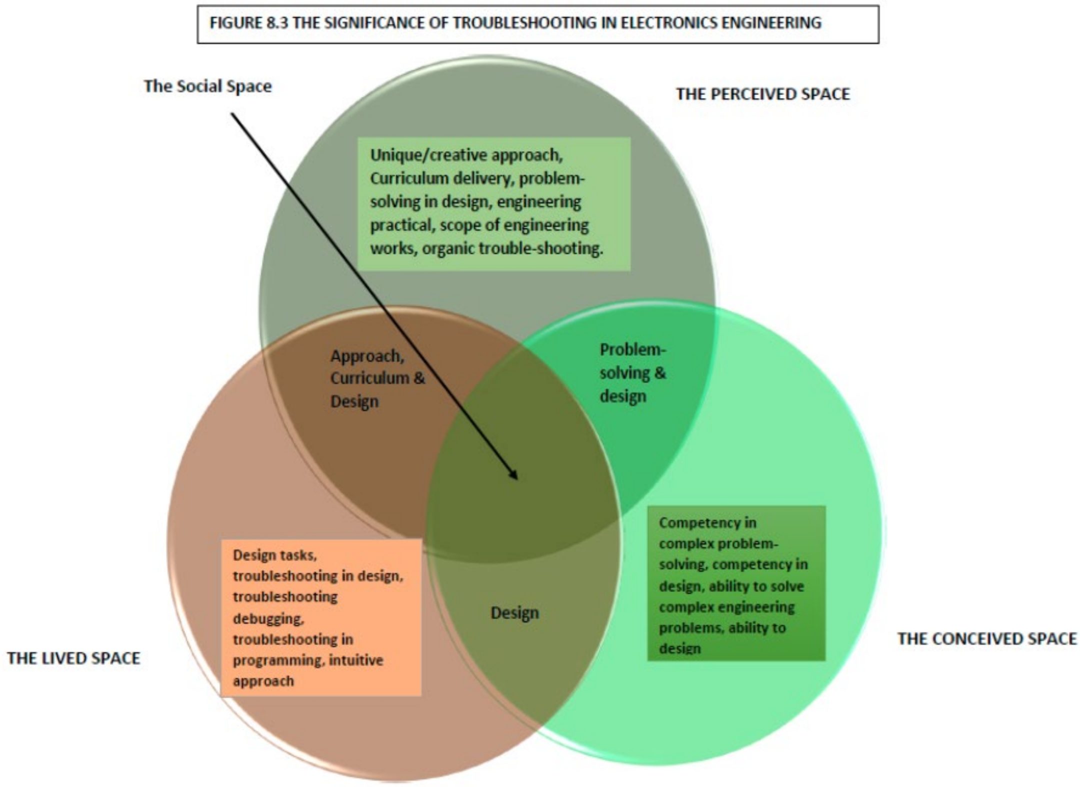


Figure 15: The significance of troubleshooting in the perceived space of an electronics engineering programme

Figure 15 shows that troubleshooting is included in the perceived space as organic troubleshooting and in the lived space of everyday practice and experiences of electronics engineering students, as embedded in design, debugging and programming. However, troubleshooting is excluded from the conceived space and the internal interaction between the conceived and the perceived, the perceived and the lived, and the conceived and the lived. In contrast, design is included in the three intersections between the three spaces in the triad as illustrated in Figure 15.

In agreement with the outcome from the study, Male et al. (2015) corroborated that design has been noticed particularly to carry considerable glamour and respectable status in the field of engineering and has been noticed explicitly in the curriculum and learning outcome. The electronics engineering official discipline curriculum is a transformed knowledge of the conceived space of the CHE and ECSA. The contents are transmitted to the perceived space and managed bureaucratically by the content of the policy in the conceived space and the authority of the government agents that provided the documents. It therefore provides justification for what is being interpreted, implemented and enacted by the electronics engineering lecturers and laboratory technicians. The students in the lived space may have a sense of the place of troubleshooting in the programme, and anticipate its essential usefulness in present practice and the future life in industry, but it is not a recognised generic skill. The students may be regularly involved in troubleshooting, but the department or faculty lecturers and laboratory technicians give necessary reinforcement; however, the major tasks of how to troubleshoot is the responsibility of the electronics engineering students. The students face the challenges and solve the emerging problems. This is a kind of lacunae to address in the university electronics engineering curriculum due to the significant place troubleshooting occupies in the electronics engineering space.

8.2.2 Creativity in the electronics engineering programme

In the 21st century, regarding universities' intellectual priorities on creativity, Lefebvre predicted the substitution of technological advancement by the user of the technology itself in everyday life (Lefebvre, 2004). The university education system is to be supplanted by availability of computers and internet facilities. Lefebvre predicted that there will be an imminent computerised daily life of technological alienation. Some participants in the perceived space believed that what engineers require in the present age is creativity and the use of computer simulation to solve engineering problems. That once engineers are creative, they have fulfilled the objectives of an engineering professional career. In contrast to this perception, Peace (2013) argued that if there is ever a time when troubleshooting will not be needed in the electronics engineering profession, it will be purely temporary. Artificial intelligence, sometimes called expert systems, might be able to solve some kind of engineering problems, troubleshooting problems included, but the place of genuine, human intelligence can never be overemphasized. In the modern world, computers may be used to aid simulation and solve some problems, but the computer does not really solve the problem, only a human being does; the computer is just a tool which can also develop faults and break down. The issue of technological creativity and advancement may not totally eliminate the place of human intelligence when it comes to troubleshooting. Peace (2013) further underpins this idea, that people who rely on artificial intelligence are able to solve some problems, but they can never be sure if they can accommodate every kind of genuine stupidity as well as artificial stupidity in electronics.

8.2.3 Structured troubleshooting approach

The perceived space of troubleshooting in the context of how the electronics engineering programme is being generally enacted showed that troubleshooting is not explicitly taught in the pedagogy of the programme. The participants perceived the programme as requiring a theory-based design approach, an organic or natural (intrinsic) approach, testing knowledge through written examinations and an approach in which design tasks are embedded. This is in contrast with studies that affirm that to be proficient in the troubleshooting skill, troubleshooting should be taught using a structured approach (Jonassen & Hung, 2006; Ross & Orr, 2009; Randal, 1998; Tufur, Evangelou & Strobel, 2012). The technicians particularly concluded that there is no skill taught as troubleshooting in the electronics engineering programme, it is purely and simply design. This indicates that the perceptions of participants about the education needed for the learning of troubleshooting corroborated each other and agreed with the curriculum statement in terms of enactment and regular practice. Findings revealed the opinion of the participant as shown below:

> *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 (P04).*
>
> *Students are given various projects to do, there is no one set project for any one, no specific course for troubleshooting where everybody diagnose the same or similar problems (P05).*

Some of the laboratory technicians' participants in the perceived space thought troubleshooting could not be taught with a structured approach in the electronics engineering programme, as observed from the excerpts above. Conversely, a study by Ottosen (2012) revealed that the idea of not making attempts to solve electronics problems through structured troubleshooting approach makes the problem solving tasks more difficult. A study by Jonassen et al. (2006) also contends that engineers tend to take a longer time to solve troubleshooting problems in practice because they were not taught the troubleshooting approach. The curriculum statement and the participants interviewed focused on solving complex engineering problem as a reason for not giving attention to structured troubleshooting. Ottosen further asserted that the simpler the problem, the easier the solution path, whereas, the more complicated the problem, the larger is the potential benefits of providing a formal approach to solve the troubleshooting problem. Hence, there seem to be no justification for not encouraging a structured or specific approach to pedagogy of troubleshooting in electronics engineering programmes.

8.3 Troubleshooting in the lived space of the university electronics engineering programme

The entire theory of space comprising of the triads is ultimately lived and practically experienced in the lived space. This section situates the third space in Lefebvre's production of space. This is the space of representation, the experienced space, the space of inhabitants and users, the underground side of social life, which is the combination of the conceived and the perceived, the mental and the physical. This is the space where the inequality mentioned by Lefebvre is manifested due to the influence from the dominant abstract space through to the physical, perceived space. This is the space where the sense of place as described by Cresswell (2011) and Agnew (2011) is directly and practically lived. The study represented this space as the space of lived experience of fourth year undergraduate electronics engineering students in the context of the place of troubleshooting in their programmes. The spaces that are designed by the CHE and ECSA, transformed and implemented by the curriculum, lecturers and laboratory technicians are lived and practically practised by the students eventually. Lived space is the active moment of Lefebvre's spatial triad. Figure 16 below shows the relationships between the lived space and the other two spaces in electronics engineering programmes. It reflected the combinations of the conceived and the perceived spaces that culminated as the everyday experiences of the students in the lived space. The lived space in this study produced the discoveries highlighted in the sub-sections below.

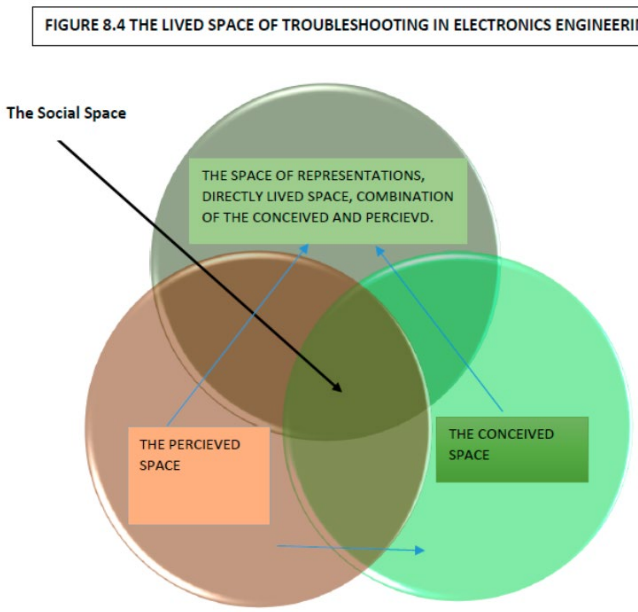


Figure 16: The relationship of the lived space to other spaces in the electronics engineering programme

8.3.1 The sense of the place of troubleshooting as embedded in students' learning experience

The outcome of the analysis of the study showed a difference in the opinion of students on the place of troubleshooting in electronics engineering programmes. The results from the study show that fourth year electronics engineering students experienced troubleshooting in all their learning experiences. The results revealed that there is a place for troubleshooting, firstly, in an intuitive manner which corroborates the lecturers and laboratory technicians' view. Secondly, the students affirmed that from their first year to final year of study and regular engagement with practical projects, there is a place for troubleshooting, it is embedded and experienced in their everyday practices. Furthermore, the study showed that troubleshooting is embedded in the context of design, project evaluation and testing, programming and debugging of software. Students' experience therefore implies that there is a sense of place for troubleshooting in the electronics engineering profession. Creswell (2009) and Agnew (2012) argue that when an event is being practised particularly by repetition of practice on a regular basis, there is a sense of place of such event. By implication, the regular sense of place of troubleshooting in everyday practice of electronics engineering students is an indication of its place in the experience of the students. It is also an indication that what is conceived by CHE and ECSA, perceived by the transformed curriculum, lecturers and laboratory technicians and the lived experience of the students should be in agreement, hence, CHE and ECSA should explicitly incorporate it.

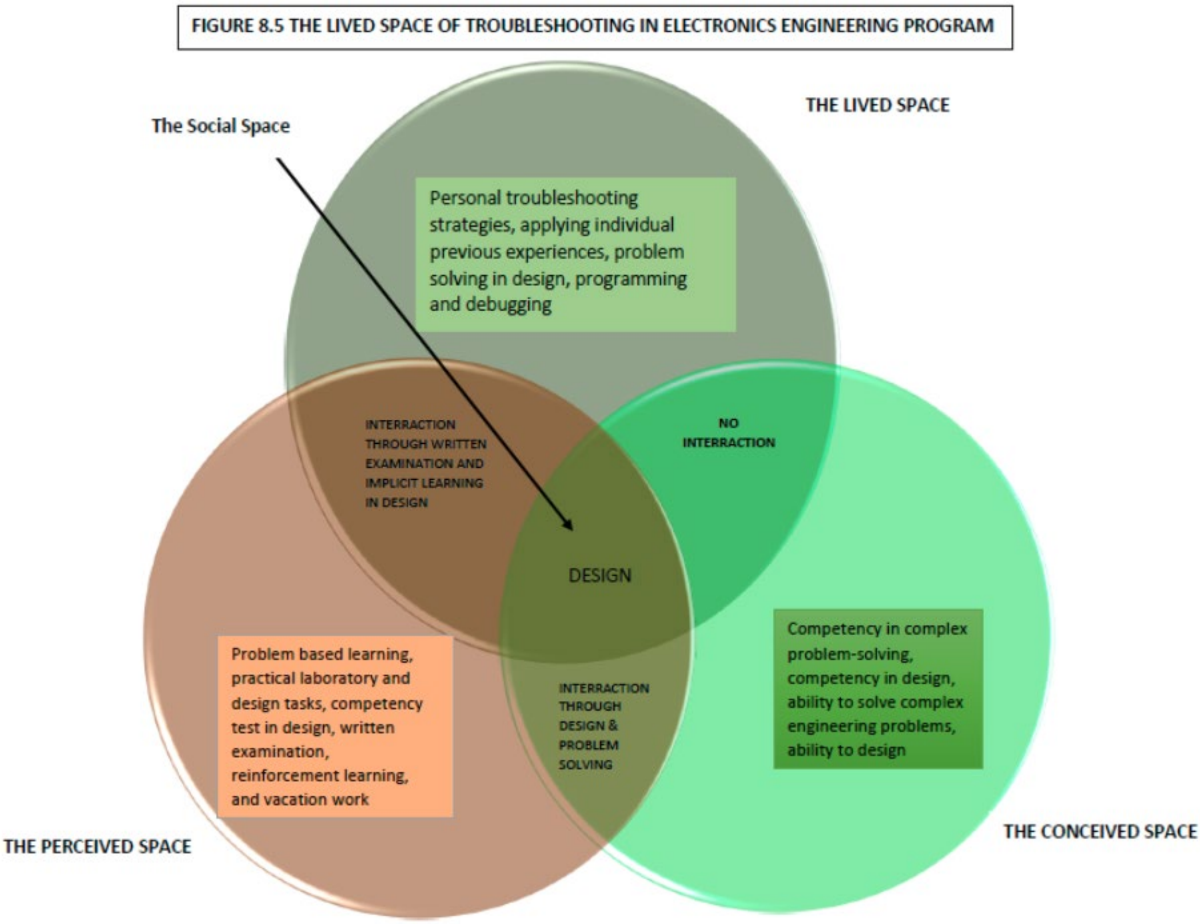


Figure 17 Contradictions in the lived space of troubleshooting in the electronics engineering programme

Figure 17 shows how troubleshooting is experienced in the lived space by fourth year electronics engineering students intuitively in design problem solving, personal troubleshooting strategies and application of previous experiences. However, there was a contradiction between what is conceived and perceived as there is no interaction between these two spaces and lived space, in terms of troubleshooting experience.

8.3.2 Explicit instruction about troubleshooting

Engineering design is perceived as the heart of electronics engineering programme and is associated with possible process and product problems, malfunctioning and faults. Despite this reality, findings revealed that most of the students' participants reported that troubleshooting is not taught explicitly to undergraduate electronics engineering students. Dounas-Frazer and Lewandowski (2017) assert that students often make mistakes or have errors in their circuit designs and need to revise these circuits through a troubleshooting process. Some students gave evidence that no one teaches them in an explicit form, they believe that troubleshooting is acquired implicitly through their intuition, personal efforts and past experiences. In contrast, studies such from Dounas-Frazer and Lewandowski (2017), Jonassen and Hung (2006), Vigil et al. (n.d) with Ross and Orr (2009) reveal that explicit instruction about troubleshooting aligned with cognitive apprenticeship paradigm of instruction and could be used to liberate students from trial and error and other time wasting unstructured approach which was practised by the electronics engineering students.

An alternative approach to address troubleshooting problems by engineers suggested by Schaafstal et al. (2000), Ottosen (2012) and Van De Bogart (2017) is the structured troubleshooting strategy. According to Schaafstal et al. (2000), structured troubleshooting is an approach "that combines a domain-independent strategy for troubleshooting with a context-dependent, multi-level, functional decomposition of systems". Basically, these authors argued that troubleshooting is first and foremost a cognitive task. It requires the knowledge, as well as the measurement skills an engineer ought to acquire about the system, to troubleshoot and carry out repairs and restoration of systems or unit of system to their proper functioning state. Ottosen (2012) further argued that failure to adopt a structured approach to troubleshooting and using the unstructured ad hoc approaches such as "trial and error" makes the process slow; solutions are easily forgotten over time and the troubleshooter ends up starting from the scratch again. Some of the student participants agreed to the fact that the reason why they used "trial and error" and spent a lot of time to solve emerging problems was because there was no direct structured troubleshooting approach they were taught. The implication is that if students are taught through the structured approach, it would produce proficient electronics engineers who will invest less time in a new task appropriation. Dounas-Frazer and Lewandowski (2017) add that instructors could engage students in articulation, coaching, modelling and fading support, but not necessarily teaching troubleshooting theory. The reality is that students are novices in troubleshooting, they are not yet experts, in order words, the apprenticeship model is still appropriate for them at this stage of their career.

8.3.3 Troubleshooting and students' experiential knowledge

While some of the students identify troubleshooting as a regular experience they encounter in electronics courses, they did not receive training that assisted them in handling the troubleshooting challenge directly. This might have limited their ability to learn how to troubleshoot. Some of them attest that troubleshooting is difficult, it requires a lot of time and analysis as shown in the excerpts below:

And a lot of the time to troubleshoot could be very difficult and hard to do because you don't know how to analyse how something could go wrong (ST03),

Often time there is no enough time to create the troubleshooting mechanism and so you have to make some efforts at it. So when doing troubleshooting often time I couldn't get any understanding of the problem that I am trying to solve when I am going for the troubleshooting in so much the areas of issues that are in the solutions that are coming up to a great understanding of the problem solving in the first place. And sometimes that makes me to really designing more things from the scratch after the troubleshooting (ST03).

I do learn this experience during practical work and work experience at the company (ST04).

It's something you learn through experience (ST02).

To address the problems, those that had gained previous experience from high school, technical college or industry try to recall from their case-library of information, the cognitive aspect of the troubleshooting process. This is an indication that they could be more proficient in the future experience if they are exposed to structured institutional-based troubleshooting experience. This corroborates the argument of Ottosen (2012) that, although troubleshooting tasks may be difficult, there is great potential benefit in providing a formal approach to solve troubleshooting problem.

8.4 Summary of chapter 8

The structure of this chapter is such that the variations in the ways participants foreground and experience troubleshooting in the electronics engineering programme through the phenomenographic analysis culminated in varieties of outcome spaces. These outcome spaces were discussed using the theoretical lens of Lefebvre's triad and entering the triad from the conceived, through the perceived, to the lived space. The concern of this study is with regard to where the place of troubleshooting is in these three theoretical spaces and, to that effect, whether there is any theoretical unity among the spaces as proposed by Lefebvre. The theoretical approach of Lefebvre unfolded three tendencies in this study. Firstly, the conceived space situated electronics engineering programme in accordance with international standards for engineering programmes through policy. The concept of policy appropriation was enshrined for electronics engineering programmes, whereby troubleshooting skills were alienated from generic engineering skills and applied competencies. Secondly, the perceived space adapted the policy through curriculum content and pedagogical appropriation. The position of troubleshooting in this space is such that, only partially, it was foregrounded and enacted informally. No explicit teaching approach to the acquisition of troubleshooting skills was afforded; hence troubleshooting is partially recognized in this space. Lastly, the lived space situated troubleshooting with a high sense of place as it is reflected in the everyday practice of electronics engineering students. Lefebvre's theoretical lens revealed a lack of unity among the three spaces in this study. An inconsistency in the relationships pertaining to troubleshooting was observed among the triads. This raised the concern on the place of troubleshooting among the multiple skills the engineer developed in the educational space of the electronics engineering programme, between the theoretical and physical space, the abstract and the concrete space, engineering science and engineering technology. It is argued that, for a balance of space, a theoretical unity of Lefebvre's theory is required.

CHAPTER 9

CONCLUSIONS

9.0 Introduction

The central objective of this thesis is to explore the place of troubleshooting in an undergraduate electronics engineering programme. The main discovery in the study was that troubleshooting has not been explicitly articulated in the electronics engineering programme in the university explored. A significant gap has been observed on the place of troubleshooting in the spaces of electronics engineering education programme. The following three research questions were raised, interrogated and analysed to address this concern using the phenomenographic analytical tool while Lefebvre's theoretical frameworks was used to answer the main research question on *what is the place of troubleshooting in a university electronics engineering programme?*. The three research questions raised from the study are:

1. Is troubleshooting being accommodated in the electronics engineering programme:
    - Policy documents - CHE and ECSA documents?
    - University electronics engineering handbook?
    - Lecturers - electronics engineering lecturers?
    - Technicians - electronics engineering laboratory technicians?
    - Students - fourth year electronics engineering students?

    c. If so, what is foregrounded in the electronics engineering programme?

    d. If not, what is foregrounded in the electronics engineering programme?
2. How should or is the electronics engineering programme being enacted by:
    - Policy documents - CHE and ECSA documents?
    - University electronics engineering handbook?
    - Lecturers - electronics engineering lecturers?
    - Technicians - electronics engineering laboratory technicians?
    - Students - fourth year electronics engineering students?
3. What informs how electronics engineering programme should or is being enacted by:
    - Policy documents - CHE and ECSA documents?
    - University electronics engineering handbook?
    - Lecturers - electronics engineering lecturers?
    - Technicians - electronics engineering laboratory technicians?

- Students - fourth year electronics engineering students?

The second-order phenomenographic analytical framework applied in analysing the data of the study pointed out different ways the phenomenon of troubleshooting was perceived by different participants. Two out of the three lecturer participants do not perceive teaching troubleshooting as necessary and as a specific engineering skill in the pedagogical approach, as they focused on theoretical "teaching to think", creativity, and, in particular, design. One other lecturer and two laboratory technicians foregrounded troubleshooting as being embedded in design, in regular delivery of the curriculum during systematic practical projects and in organic troubleshooting. The phenomenographic categories of description in the study revealed the different ways in which these participants are aware of troubleshooting in electronics engineering programmes. The outcome space that emerged from the categories of description from participants' narratives and that was synthesized into themes, however, provided a better understanding of the reality of the phenomenon of troubleshooting in the electronics engineering education programme as it showed the interactions and relationship between the categories. The outcome space provided evidence that, in reality, troubleshooting is there in the electronics engineering education programme, but the participants perceived it differently and in different ways. Some kind of hierarchical structure of understanding of the place of troubleshooting was identified from the data provided by the lecturers and technicians and finally by the students. Through the phenomenographic analytical tool, the outcome of different perspectives was brought up, which served as a platform to further seek to determine the real place of the phenomenon of troubleshooting in the electronics engineering education programme. The findings from the phenomenographic analysis revealed four basic outcomes, as presented below:

- An outcome space which foregrounds the following conception about troubleshooting in university electronics engineering programme; the engineering approach to teaching and learning, curriculum delivery in engineering, and design process as where troubleshooting skill is enacted;
- An outcome space which foregrounds electronics engineering programme as solving complex engineering problems, engaging in pure design tasks and organic troubleshooting;
- An outcome space of enactment of electronics engineering programme through individual-based practice, theory-based practice and design-based practice; and

- An outcome space of what informs the enactment of electronics engineering programme as engineering learning outcomes – a design-based reason and engineering programme curriculum – an individual, theory and design-based reason.

These findings served as the basis to theorise the phenomenon of troubleshooting in electronics engineering, using Lefebvre's theoretical framework. Lefebvre's theoretical framework of the production of space consisting of the triads of the conceived, the perceived and the lived space, which underpins the study, is presented in Figure 18 below.

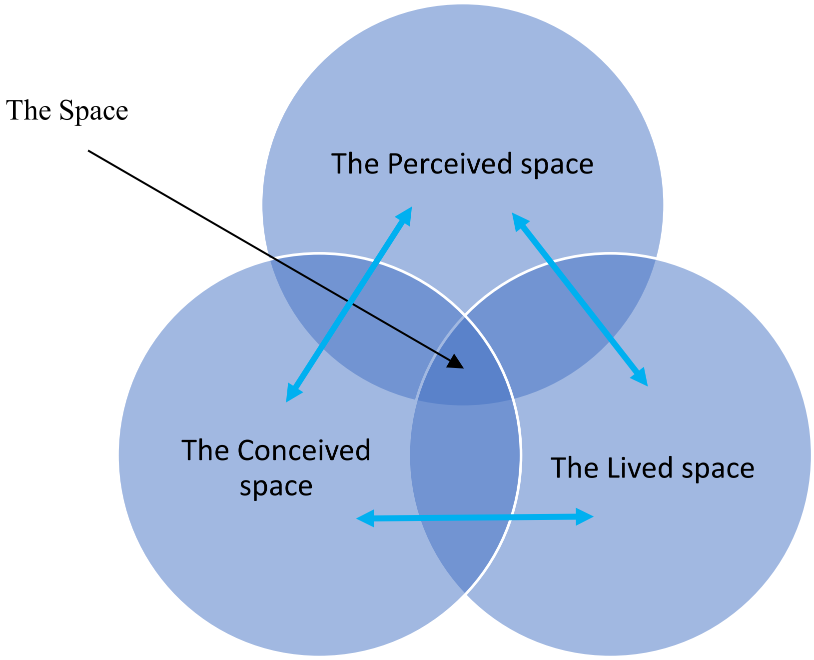


Figure 18: Study model from Lefebvre's theory of the production of space

The conceived space comprised the CHE and ECSA, the perceived space consisted of university electronics engineering curriculum, the lecturers and the laboratory technicians, while the lived space comprised the fourth year electronics engineering students. CHE and ECSA constituted the conceived space of the professionals and planners, because this is where the hegemony of engineering education originates. The curriculum, lecturers and laboratory technicians constituted the perceived space, the physical space; this is where the thoughts of the educational planners are transformed and brought to action. Lastly, the lived space is made up of the ultimate lived experiences of fourth year electronics engineering students where the educational knowledge perceived and conceived become actively lived and experienced in everyday practice. The findings on the place of troubleshooting in this electronics engineering programme were discussed, based on the theoretical framework of Lefebvre and other literature relevant to the study, in order to situate the place of troubleshooting within the three spaces of the programme. Lefebvre's theory brought to fore the internal relationships and interactions between these three spaces. In the first space of CHE and ECSA in the electronics engineering programme, troubleshooting was not afforded any noticeable significance; it was not included in the required generic competency skills, knowledge and measurable outcomes for electronics engineering programmes. The second space of the electronics engineering curriculum contained in the university handbook, the lecturers and the laboratory technicians, presented troubleshooting as being concealed within the electronics engineering programme. The university curriculum did not afford any noticeable significance in terms of content and pedagogical requirements; about 67% (two out of three) of lecturer participants did not afford it any significance because of what they regarded as specialized curriculum delivery, such as "they teach students how to think creatively, how to create and invent new engineering process and products". However, the other 33% (one out of three) of lecturer participants and 100% (two) of technician participants afforded it some significance in terms of what they foregrounded and enacted through the design process, through organic troubleshooting, reinforcement and students' individual learning experiences. Some of these participants perceived the electronics engineering space as purely for design and that engineering skills stops and ends at designing, because assigned engineering tasks differ from that of the technicians in the industry. However, the third space of everyday lived experience was more significant as it was found that troubleshooting was unpacked in a different way by the fourth-year electronics engineering students. In this space, troubleshooting was afforded a significant space as it was embedded in the everyday lived experiences of electronics engineering students through intuitive and individual learning style, design practices, debugging and programming processes. For instance, troubleshooting was tagged as an integral part of programming which is practised in computer and software aspects of electronics engineering. Students often engaged in a troubleshooting process when faults or syntax errors occur in programming or when any of the software-hardware-link components broke down. With respect to design, the students signalled that troubleshooting is embedded in regular engineering design processes. Most engineering design processes at one time or the other usually develop a series of faults and problems which had led students to engage in regular troubleshooting practices in an attempt to repair the faults and make the design work.

Turning the spotlight to debugging, this is another term that was used interchangeably with troubleshooting by the students, particularly in computer programming, while dealing with detecting programming faults and correcting errors using computer programming codes. Finally, in evaluating and testing design projects, troubleshooting is inherent, meaning that troubleshooting is existing as a permanent and essential characteristic of design projects; it is built-in the engineering testing and evaluation of design. Students affirmed that the whole complete project designed may not work or some section of the design system may develop faults, thereby requiring troubleshooting skills to repair it and remove the abnormality experienced. The three spaces in Lefebvre's theoretical framework presented different perspectives of the place of troubleshooting in the electronics engineering education programme, indicating a lack of the theoretical unity that Lefebvre argued for in the production of space. The focus of the unity is in the spread and recognition of troubleshooting as equally significant across the three spaces of the conceived, the perceived and lived. The phenomenon of troubleshooting in the electronics engineering education programme should be afforded the same significance in the moments of production, thereby removing the tendency for dominance of the abstract space which does not clearly recognize troubleshooting in engineering programmes. The following implications were therefore raised from the discussion.

9.1 Implications of the study for CHE and ECSA policy

i. Troubleshooting is not included in the required generic electronics engineering competency skills and exit level measurable outcomes. This non-affordance of space for troubleshooting was noticed in the CHE (2015) Qualification Standard for Bachelor of Engineering and Bachelor of Science in Engineering and ECSA (2017) Qualification Standard for Bachelor of Science in Engineering and Bachelor of Engineering (BSc(Eng)/BEng).

ii. The more theory-based and managerial competencies introduced into electronics engineering have implications on the practical-based competencies prescribed for electronics engineering programmes. Though, technology is dynamic and evolutive in nature, yet the culture practice-based engineering demands significant attention while revising engineering programme from time to time. Out of the latest 11 competency skills in both the CHE and ECSA documents, 5 were hard-core technical skills and 6 were soft-skill. The technical hard-core skills and competencies include problem solving, application of scientific and engineering knowledge, engineering design, investigation, experiments and data analysis, and engineering methods, skills and tools and information technology, while soft skills had increased to six, including professional and technical communication, sustainability and impact of engineering activities, individual, team and multidisciplinary working, independent learning ability, engineering professionalism and engineering management.

iii. The increase in soft skills have implications on the provision for core engineering skills in engineering programme. Though, some tasks are being automated, it should not take the place of core engineering skills that requires advancement of human intelligence in practice. As can be inferred from (ii) above, the content of hard-core competencies should not be withdrawn to create space for the addition of soft-core managerial skills, rather, it should be an inclusion and advancement of more hard-core skills. This was corroborated by one of the lecturer participants in a given response evidenced in the excerpt below:

    In actual fact, there was pressure from ECSA. ECSA required us to introduce professional courses, so engineers often end up in managerial position, so we are going to introduce courses on professional practice and economics. So we are going to drop quantum mechanics for professional courses (P03)

iv. Troubleshooting is a key hard-core technical skill that could make electronics engineering profession more robust and fascinating for prospective students. As asserted by Jonassen (2011) and Ottosen (2012), troubleshooting remains one of the most common hard-core problem solving skills for engineering profession.

9.2 Implications of the study for institutional curriculum, electronics engineering lecturers and laboratory technicians

i. The study reveals that, although troubleshooting for novice troubleshooters usually takes time, this could be reduced considerably if the lecturers and laboratory technicians could adopt and consider the structured troubleshooting approach

ii. The electronics engineering institutional curriculum should embrace the key values of the skill of troubleshooting in design and regular laboratory practical and therefore afford it a space in the curriculum content. Findings from the study affirmed that troubleshooting emerged regularly in the laboratory practical students usually performed. One of the lecturer participants concur on this point as evidenced from the statement excerpt below: *Troubleshooting task is specifically by giving the students two practical in their laboratories in their third year. In second year we have four experiments and troubleshooting is involved because they design their own circuit on the breadboard (P02).*

iii. Pedagogically, troubleshooting should be appropriated in the design process, product and evaluation techniques. Findings from the study attested that troubleshooting was practised by students in the process of systematic evaluation of circuits to identify discrepancies that occurred in circuits given by laboratory technicians. This was highlighted by the participants as follow: *We also check all the components separately. Then they will check the modules; So the troubleshooting comes up as they engage in their work (P02)*

iv. Problems and faults are inevitable in the electronics engineering programme circuit designs, analogue and digital circuit constructions, as affirmed by Dounas-Frazer and Lewandowski (2017)) and validated by findings from participants as revealed in the excerpts below: *So when they are designing and assembling these components on the board, then they are facing some problems and then what happens, they come to me and can also take some help from their friends… then we make some troubleshooting efforts like what is the problem? Are the components ok, is it not burnt component, is it destroyed components? (P02)*

    Therefore, the programme should be designed to anticipate and solve such problems through a formal troubleshooting approach.

v. The electronics engineering programme should be designed to handle the lacunae in the curricular provision for troubleshooting, especially between academic institutions and industry workplace. As was noticed in the CHE and ECSA documents, troubleshooting was not afforded a space in the stipulated skills and knowledge required for an electronics engineering programme (CHE, 2015; ECSA, 2017).

vi. A structured troubleshooting teaching approach has the tendency to increase electronics engineering problem solving skills while designing, debugging and programming; it should thus be embraced in the programmes. The participant gave clear evidence that; *there is no specific training for troubleshooting (P04)*, and *….no specific course for troubleshooting whereby students diagnose similar problems (P04).* However, previous studies affirmed that a structured approach to learn troubleshooting added value to troubleshooting proficiency and competency (Jonassen& Hung, 2006; Ross & Orr, 2009; Tufur, Evangelou & Strobel, 2012; Ottosen, 2012)

vii. Since troubleshooting is inherently part of engineering skills, lecturers and laboratory technicians should refocus on its usefulness and appropriation in principle and practice. Participants affirmed that students encountered with and picked troubleshooting in their training as illustrated in the excerpt thus: *Troubleshooting is a requirement that they pick up in their training (P04);and so troubleshooting comes up in the lab, when they are designing the circuit (P05). They are required to be able to figure out though the knowledge of their theory, to figure out why it's not working in the design (P04).*

viii. Electronics engineering lecturers and laboratory technicians should be prepared to assess and measure students' ability to troubleshoot as a professional to get them better ready for workplace experience. Since troubleshooting was not recognized as one of the measurable outcome skills, there was no assessment method assigned to it in electronics engineering programmes. This is required to be part of the programme goal and objective.

ix. The study also suggests that electronics engineering programme members should work with advisory boards and employers on the design and development of an electronics engineering curriculum that should consider placing special emphasis on these "top cluster" competencies such as problem-solving which include troubleshooting skills.

9.3 Implications for electronics engineering students

i. There is no student that can do engineering design without troubleshooting. It should be anticipated in the programmes. Findings from students revealed that design projects are not completed without troubleshooting practice, as was attested to in the following excerpt: *Troubleshooting is basically after you have completed a system and it's not working, you have to find out where the problem is, going through the process of debugging. You check each component to find out what's causing the problem (ST03).*

ii. Problems, faults and circuit failures are inevitable in everyday engineering process and practice; students must anticipate this and be prepared to address the troubleshooting aspects practically and holistically. Evidence from the findings of the study revealed that every other thing on a given design may work theoretically, but may not function practically as established by a participant thus: *Everything seems to work on paper, but when we try doing it, nothing worked. So we had to test it bit by bit until we found the problem (ST06).*

iii. The place of a cognitive apprenticeship model cannot be overemphasized for electronics engineering students who are novices in troubleshooting skills. It should be embraced in principle and practice. Previous studies have made contribution to this assertion (Peace, 2013; Dounas-Frazer & Lewandowski, 2017)

iv. Electronics engineering students are novices in engineering problem solving and troubleshooting skills, they are required to be trained differently from the approach used in training experts, so that they can enter into the workforce more confidently prepared.

v. Proficiency in troubleshooting requires anticipating the need to troubleshoot and hence perform better in circuit building and maintenance of products. Findings from the study showed that students were not taught how to troubleshooting as evidenced from the excerpts; *there is no specifics that teach you how to troubleshoot (ST01).*

vi. Electronics engineering students should be assessed on their ability to troubleshoot as a professional engineer.

9.4 Implications for theory

As Lefebvre contended for and supported a balance between the three moments in the production of space, this study advocates for a balance between the three moments of the conceived, perceived and lived spaces in the production of space for troubleshooting in university electronics engineering programme. That there should be a balance and a unity between what CHE and ECSA conceive, what the university engineering education programme curriculum, lecturers, laboratory technicians perceive and what the electronics engineering students live and practise in the context of troubleshooting in the electronics engineering programme. Rather than the space of electronics engineering programme being dominated by the forces of the theoretical, the mental space of CHE and ECSA and the place of troubleshooting being isolated out of the context of electronics engineering programmes, there should be a theoretical unity between the three spaces of the conceived, perceived and the lived which are involved in the place of troubleshooting in undergraduate electronics engineering programmes. In other words, what is conceived by CHE and ECSA should agree with what is perceived by the institutional curriculum lecturers and technicians, and what is lived by the fourth year electronics engineering students theoretically and in practice.

This study has shown that, although design problems are commonly identified by these three spaces as the heart of electronics engineering programme, as also asserted by literatures reviewed and discussed in Chapter 8, there is another problem in the space of engineering education programme yet to be afforded a space and the theoretical unity as design problem. The troubleshooting problem has been identified as one of the varieties of other problems electronics engineers do solve, but has not been afforded significance in all the three spaces harmoniously. Troubleshooting has been afforded significance partly in the perceived space and largely in the lived space, without being noticed by the dominant space in the university engineering education programme in South Africa. This study has provided a theoretical foundation for this practice, specifically in an electronics engineering education programme in South Africa, the location of the study. In spite of this fact, there are other varieties of soft skills such as professional and management skill which calls for a different set of experience and cognitive skills which are afforded significance and are being added to electronics engineering programme by the conceived space for electronics engineering students. The skill of troubleshooting is a hard-core skill and of paramount importance to electronics engineers' professional attributes. Unfortunately, troubleshooting has been alienated from the space of electronics engineering programmes by the conceived space, but this study tends to support the argument that this does not imply that troubleshooting is not needed or required in the programmes. In as much as the end product of the training offered by electronics engineering programme; which is the lived space of the students, experienced and practised troubleshooting regularly but informally, it shows its place is significant and therefore should be advocated for and afforded a significance among the three spaces. Particularly the conceived space of CHE and ECSA, which has hegemony over other spaces, should take the responsibility for this advocacy and subsequent implementation in other spaces. In spite of the fact that CHE and ECSA documents, the university curriculum guide (content and pedagogy), lecturers and laboratory technicians have not explicitly declared the inclusion of troubleshooting in the programme, that does not and has not eliminated its relevance for electronics engineering students and its professional usefulness. The lecturers and technicians advanced various reasons for not affording troubleshooting a space in engineering training. For instance, findings showed that the lecturers rated engineers very highly and as different professionally from scientists and technologists, and considered this reason for not affording troubleshooting a space in electronics engineering. That engineers are trained to be creative and creativity cannot be taught, is premised on strong intuition. Furthermore, the lecturers and laboratory technicians assumed that engineers work with high level complex engineering tasks while technologists work at a lower level of engineering tasks. In addition, the curriculum-assigned tasks for engineers are wider than those of technologists, such that engineers do not have to bother with lesser tasks that are meant for technologists, particularly what are required of them in industrial workplaces. The implication is that a hierarchy of roles in engineering training has been created between engineers and technologists. The challenge is how can positive change be introduced to reinforce the engineering students who are regularly confronted with troubleshooting problems while undergoing training and beyond while entering the work force as a novice in spite of the hierarchical structure. This is a call for transformation of the culture in electronics engineering education. Otherwise, engineers with little or no anticipation for hard-core troubleshooting skills opt for other professions such as in management or the banking industry, leaving behind professional gaps of competent personnel in engineering careers. The electronics engineering students who occupy the lived space affirmed that troubleshooting is important, regularly experienced and the skill sometimes become difficult to practise due to lack of cognitive knowledge about it. This scenario calls for a rethinking of electronics engineering programme in the context of troubleshooting skills in the programmes.

The observed contradictions in the place of troubleshooting in electronics engineering programmes can be removed by adopting the logical relationships of inclusion and exclusion in Lefebvre's theory of production (Lefebvre, 2012, pp. 293-294). Lefebvre proposed that the relationships among the three spaces can be amended by the inclusion of one subject and excluding the other in the order of significance, or else, if such is not possible, the relationship could be mutually exclusive. In other words, if the exclusion of one is not possible for the inclusion of the other, the duo should co-exist equally and mutually. Drawing from this inspiration, due to the significance of troubleshooting, it could be afforded inclusion in electronics engineering programme in the three spaces while some theory-based courses on economics or management in the curriculum should be excluded. Otherwise, the status quo is maintained but with troubleshooting afforded a significance in the programme curriculum as other skills included in a mutually exclusive relationship. Hence, a balance of space that accommodates the troubleshooting skill in undergraduate electronics engineering is obtained. This would mean that the space of CHE, ECSA, the university engineering institutional curriculum, lecturers, and laboratory technicians and students will provide a balanced sense of place for troubleshooting in the electronics engineering programme, which will not be restricted to partly the perceived space and largely the lived space as seen in this study.

The balance in this context could also suggest a re-thinking of the place of troubleshooting in the electronics engineering programme. This study may suggest that the university engineering education planners should think of an applicable and relevant approach for the acquisition of the skill of troubleshooting, based on its significance and relevance in the lived space of electronics engineering students. This could be done by reasoning in the light of all the observed implications of this study and revive the practical-based engineering practice in the context of troubleshooting. This thesis has demystified the assumption of the place of troubleshooting in electronics by locating where the skill is found among the spaces of an electronics engineering education programme. The troubleshooting skill which has been assumed not to have a place formally in electronics engineering was found to occupy a significant place, particularly in everyday lived experiences of the students who are the end product of an electronics engineering training programme. It has also argued for a balance and a theoretical unity in the production of space among the three spaces in the context of troubleshooting in electronics engineering education programmes.

9.5 Limitations and suggestions for further studies

This study is limited to an exploratory case study on the place of troubleshooting in undergraduate electronics engineering programmes. Further studies could be conducted to involve more participants from different engineering universities, comparing conventional universities with universities of technology within South Africa and outside South Africa. Studies could also be conducted to include industry collaboration with university advisory board on troubleshooting in the electronics engineering programmes. This would afford generalizability of the findings of this study. The study could also be extended to other disciplines in engineering education programmes. The theory of space, as presented by Lefebvre's production of space, could also be extended to other contexts in engineering education.

LIST OF REFERENCES

ABET. (2017). *Criteria for accrediting engineering programmes (2018-2019)*. Baltimore, MD: Accrediting Board for Engineering and Technology.

Agnew, J. (2011). Space and place. In J. Agnew and D. Livingstone (eds.) *Handbook of geographical knowledge*, (pp. 316-331). London: Sage.

Åkerlind, G. S. (2012). Variation and commonality in phenomenographic research methods. *Higher Education Research & Development, 31*(1), 115-127.

Alant, B. P. (2001). *A case study of university students' experiences of introductory physics drawn from their approaches to problem solving.* (Doctor of Philisophiae), University of Western Cape, Western Cape.

Attia, J., Tembely, M., Hobson, L., & Obiomon, P. (2018). Hands-on learning in multiple courses in electrical and computer engineering. Paper presented at the proceedings of the 2018 Gulf-Southwest section Annual Conference, The University of Texas, Auston.

Bell, J. (2014). *Doing your research project: A guide for first-time researchers*. Berkshire McGraw-Hill Education (UK).

Bowden, J. A. (2000). The nature of phenomenographic research. In J. Bowden & E. Walsh (Eds.), *Phenomenography* (pp. 1–18). Melbourne: RMIT University Press.

Brumm, T., Guardiola, R., Hanneman, L., & Mickelson, S. (2001). *Development of workplace competencies sufficient to measure ABET outcomes.* Paper presented at the ASEE Annual Conference Proceedings, Iowa State University, Iowa.

CAES. (2016). *Electronics engineering handbook for 2016*. Durban, South Africa: College of Agriculture, Engineering and Science.

CAPS. (2014). *Curriculum and assessment policy statement (CAPS) Grades 10-12. Electrical technology*. Pretoria, South Africa: Department of Basic Education.

CHE. (2015). *Qualification standard for Bachelor of Engineering and Bachelor of Science in Engineering*. Pretoria, South Africa: Council on Higher Education.

Ching-zon, Y., Ching-Fang, L., Huang , G.-F., & Chang, Y. (2004). A study of thinking process on troubleshooting of single-chip microcomputer system. Paper presented at the International Conference on Engineering and Research "Progress through Partnership. VSB-TUO, Ostrava.

Clough, G. W. (2004). *The engineer of 2020: Visions of engineering in the new century*. Washington, DC: National Academy of Engineering,.

Cohen, L., Manion, L., & Morrison, K. (2011). Research methods in education. New York: Routledge.

Collier-Reed, B., & Ingerman, Å. (2013). Phenomenography: From critical aspects to knowledge claim. In M. Tight & J. Huisman (Eds.), *International Perspectives on Higher Education Research* (Vol. 9, pp. 243-260): Emerald Group Publishing Limited. DOI: 10.1108/S1479-3628(2013)0000009016

Crawford, S. (1996). The making of the French engineer. In P . Meiksins and C. Smith (Eds.), *Engineering labour: Technical workers in comparative perspective* (pp.98-131). London: Verso.

Crawley, E., Malmqvist, J., Ostlund, S., & Brodeur, D. (2007). Rethinking engineering education. *The CDIO Approach, 302*, 60-62.

Cresswell, T. (2011). Place–Part I. *The Wiley-Blackwell companion to human geography*, 235-244. Egham, UK: Elsevier.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*. Thousand Oaks CA: Sage.

Creswell, J. W. (2014). Research design: qualitative, quantitative, and mixed methods approaches. Thousand Oaks CA: Sage.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*: Thousand Oaks CA: Sage.

Crismond, D. (2013). Troubleshooting: A bridge that connects engineering design and scientific inquiry. *Science Scope, 36*(6), 74-79.

D'Almaine, G. F., Manhire, B., & Atteh, S. O. (1997). Engineering education at South Africa's technikons. *Journal of Negro Education*, *66*(4), 434-442.

Delaney, D. (2008). *Territory: A short introduction*. Oxford: Blackwell publishing.

Denzin, N. K., & Lincoln, Y. S. (2011). *The SAGE handbook of qualitative research*: Thousand Oaks CA: Sage.

Department of Labour. (2005). *Sector education and training*. South Africa. Pretoria: Department of Labour.

Dounas-Frazer, D. R., & Lewandowski, H. (2016). Nothing works the first time: An expert experimental physics epistemology. *Physical Review Physics Education Research arXiv preprint arXiv:1606.05389*. [physics.ed-ph] 17 June 2016.

Dounas-Frazer, D. R., & Lewandowski, H. (2017). Electronics lab instructors' approaches to troubleshooting instruction. *Physical Review Physics Education Research, 13*(1), 010102.

Dounas-Frazer, D. R., Van De Bogart, K. L., Stetzer, M. R., & Lewandowski, H. (2015). The role of modeling in troubleshooting: An example from electronics. *arXiv preprint arXiv:1507.03939*.

Dounas-Frazer, D. R., Van De Bogart, K. L., Stetzer, M. R., & Lewandowski, H. (2016). Investigating the role of model-based reasoning while troubleshooting an electric circuit. *Physical Review Physics Education Research, 12*(1), 010137.

Durban University of Technology. (2016). *Electronics engineering handbook for 2016*. Durban: Department of Electronics Engineering.

ECSA. (2017). *Qualification standard for Bachelor of Science in Engineering*. Pretoria, South Africa: Engineering Council of South Africa.

Elden, S. (2002). Through the eyes of the fantastic: Lefebvre, Rabelais and intellectual history. *Historical Materialism, 10*(4), 89-111.

Elden, S., Lebas, E., & Kofman, E., (2003). *Henri Lefebvre key writings*. New York: Continuum.

Elden, S. (2004). *Understanding Henri Lefebvre*: London, New York: A&C Black.

Estrada, T., & Atwood, S. A. (2012). *Factors that affect student frustration level in introductory laboratory experiences.* Paper presented at the American Society for Engineering Education. San Antonio, Texas.

Flesher, J. W. (1993). An exploration of technical troubleshooting expertise in design, manufacturing, and repair contexts. *J. Ind. Teach. Educ.* 31(1): 34–56.

Flesher, J. W. (1993). *Context and expertise: The case of electronic troubleshooting*. Paper presented at the Annual Meeting of the American Educational Research Association, Atlanta, GA.

Fraenkel, J. R., Wallen, N. E., & Hyun, H. (2012). *How to design and evaluate research in education*. (Vol. 7). New York: McGraw-Hill.

Gispen, K. (2002). *New profession, old order: Engineers and German society, 1815-1914*. New York: Cambridge University Press.

Hochholdinger, S., & Schaper, N. (2013). Training troubleshooting skills with an anchored instruction module in an authentic computer based simulation environment. *Journal of Technical Education (JOTED), 1*(1).

IDC. (2016). Troubleshooting, Practical Industrial Electronics for Engineers and Technicians. Retrieved from: www.idc-online.com.

Jansen, J. D., & Reddy, V. (1994). *Curriculum Analysis. Paper presented at the workshop entitled 'Curriculum Development' held at the Penisula Technikon. Cape Town, South Africa.*

Johnson, S. D. (1995). *Understanding troubleshooting styles to improve training methods.* Paper presented at the American Vocational Association Convention. Denver, CO.

Jonassen, D. (2011). Supporting problem solving in PBL. *Interdisciplinary Journal of Problem-based Learning, 5*(2), 8.

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education, 95*(2), 139-151.

Jonassen, D. H. (2010). *Research issues in problem solving.* Paper presented at the 11th International Conference on Education Research.

Jonassen, D. H., & Hung, W. (2006). Learning to troubleshoot: A new theory-based design architecture. *Educational Psychology Review, 18*(1), 77-114.

Jones, J. C., & Ertas, A. (1996). *The engineering design process*. New Jersey: Wiley Hoboken.

Jørgensen, U. (2007). Historical accounts of engineering education. In E. Crawley, J. Malmqvist, S. Ostlund, & D. Brodeur (Eds). *The CDIO Approach Rethinking engineering education* (pp. 216-240). New York: Springer.

Kester, L., Kirschner, P. A., & Van Merriënboer, J. J. (2004). Information presentation and troubleshooting in electrical circuits. *International Journal of Science Education, 26*(2), 239-256.

Kester, L., Kirschner, P. A., & van Merriënboer, J. J. (2006). Just-in-time information presentation: Improving learning a troubleshooting skill. *Contemporary Educational Psychology, 31*(2), 167-185.

Khan, S. H. (2014). Phenomenography: A qualitative research methodology in Bangladesh. *International Journal on New Trends in Education and Their Implications, 5*(2), 34-43.

Kloot, B., & Rouvrais, S. (2017). The South African engineering education model with a European perspective: History, analogies, transformations and challenges. *European Journal of Engineering Education, 42*(2), 188-202.

Larsson, J., & Holmström, I. (2007). Phenomenographic or phenomenological analysis: Does it matter? Examples from a study on anaesthesiologists' work. *International Journal of Qualitative Studies on Health and Well-being, 2*(1), 55-64.

Lefebvre, H. (1991). *Critique of everyday life* (Vol. 2). London: Verso.

Lefebvre, H. (2004). *Rhythmanalysis: Space, time and everyday life.* London: A&C Black.

Lefebvre, H. (2009). *Dialectical materialism.* Minneapolis MN: University of Minnesota Press.

Lefebvre, H., & Nicholson-Smith, D. (1974). *The production of space*. Oxford: Basil Blackwell.

Lefebvre, H., & Nicholson-Smith, D. (1984). *The production of space*. Oxford: Basil Blackwell.

Lefebvre, H., & Nicholson-Smith, D. (1991). *The production of space*. Oxford: Basil Blackwell.

Lefebvre, H., & Nicholson-Smith, D. (2012). *The production of space* (Vol. 142). Oxford: Basil Blackwell.

Lincoln, Y. S., Lynham, S. A., & Guba, E. G. (2011). Paradigmatic controversies, contradictions, and emerging confluences, revisited. In N. K. Denzin & Y. S. Lincoln (Eds.), *The Sage handbook of qualitative research,* (pp. 97-128). London: Sage.

Lord, M. (2010). Not what students need. *Prism* (*January*), *19*(5) 44-46.

MacPherson, R. T. (1998). Factors affecting technological trouble shooting skills. *Journal of Industrial Teacher Education*, *35*(4), 5-28.

Male, S., Bush, M., & Chapman, E. (2010). Perceptions of competency deficiencies in engineering graduates. *Australasian Journal of Engineering Education, 16*(1), 55-68.

Male, S. A. (2011). Generic engineering competencies: A review and modelling approach. *Education Research and Perspectives, 37*(1), 25.

Marton, F. (1981). Phenomenography – describing conceptions of the world around us. *Instructional Science, 10*(2), 177-200.

Marton, F. (1986). Phenomenography – a research approach to investigating different understandings of reality. *Journal of Thought*, *21*(3), 28-49.

Marton, F. (1988). Phenomenography: A research approach to investigating different understandings of reality. In R. R. Sherman and R. B. Webb (Eds.), *Qualitative research in education: Focus and methods* (pp. 143-161). London: Routledge Falmer.

Marton, F., & Booth, S. (2013). *Learning and awareness*. New York: Routledge.

Marton, F., & Booth, S. A. (1997). *Learning and awareness*. Mahwah NJ: Lawrence Erlbaum.

Marton, F., Tsui, A. B., Chik, P. P., Ko, P. Y., & Lo, M. L. (2004). *Classroom discourse and the space of learning*. New York: Routledge.

Massey, D. B. (1994). *Space, Place, and Gender*. Minneapolis MN: University of Minnesota Press.

Merrifield, A. (2006). *Henri Lefebvre: A Critical Introduction*. New York: Taylor & Francis.

Merrifield, A. (2013). *Henri Lefebvre: A critical introduction.* New York: Routledge.

Middleton, S. (2017). Henri Lefebvre on education: Critique and pedagogy. *Policy Futures in Education, 15*(4), 410-426.

Nixon, A., & Power, C. (2007). Towards a framework for establishing rigour in a discourse analysis of midwifery professionalisation. *Nursing Inquiry, 14*(1), 71-79.

Osanloo, A., & Grant, C. (2016). understanding, selecting, and integrating a theoretical framework in dissertation research: Creating the blueprint for your "house". *Administrative Issues Journal: Connecting Education, Practice, and Research, 4*(2), 1-15.

Ottosen, T. J. (2012). *Solutions and heuristics for troubleshooting with dependent actions and conditional costs.* Aalborg, Denmark: Department of Computer Science, Aalborg University.

Pahl, G., & Beitz, W. (2013). *Engineering design: A systematic approach*. Darmstadt, Germany: Springer Science & Business Media.

Pandey, S. C., & Patnaik, S. (2014). Establishing reliability and validity in qualitative inquiry: A critical examination. *Jharkhand Journal of Development and Management Studies, 12*(1), 5743-5753.

Passow, H. J. (2012). Which ABET competencies do engineering graduates find most important in their work? *Journal of Engineering Education, 101*(1), 95-118.

Pate, M. L., & Miller, G. (2011). Effects of think-aloud pair problem solving on secondary-level students' performance in career and technical education courses. *Journal of Agricultural Education, 52*(1), 120-131.

Pate, M. L., Wardlow, G. W., & Johnson, D. M. (2004). Effects of thinking-aloud pair problem solving on the troubleshooting performance of undergraduate students in a power technology course. *Discovery, The Student Journal of Dale Bumpers College of Agricultural, Food and Life Sciences, 5*(1), 59-64.

Pate, M. L., & Young, C. (2014). Compact power equipment troubleshooting training: formative assessment using think-aloud pair problem solving. *NACTA Journal, 58*(3), 256-261.

Pease, R. A. (2013). *Troubleshooting analog circuits: Edn series for design engineers*. MA: Butterworth-Heinemann.

Petersen, I.-h., Kruss, G., McGrath, S., & Gastrow, M. (2016). Bridging skills demand and supply in South Africa: The role of public and private intermediaries. *Development Southern Africa, 33*(3), 407-423.

Quick, R. D. (2003). *Troubleshooting skills can be learned*. Manufacturing Solutions International. Retrieved from http://www.mt-online.com/. Retrieved 02 December, 2013.

Ramadi, E., Ramadi, S., & Nasr, K. (2016). Engineering graduates' skill sets in the MENA region: A gap analysis of industry expectations and satisfaction. *European Journal of Engineering Education, 41*(1), 34-52.

Reynolds, T. S., & Seely, B. E. (1993). Striving for balance: A hundred years of the American Society for Engineering Education. *Journal of Engineering Education, 82*(3), 136-151.

Rhude, W. (n.d). Electrical troubleshooting and fault finding. Retrieved from http://www.pemms.co.uk/maintenancearticles/electrical_troubleshooting.html

Ross, C., & Orr, R. R. (2009). Teaching structured troubleshooting: Integrating a standard methodology into an information technology program. *Educational Technology Research and Development, 57*(2), 251-265.

Schaafstal, A., Schraagen, J. M., & Van Berl, M. (2000). Cognitive task analysis and innovation of training: The case of structured troubleshooting. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 42*(1), 75-86.

Shields, R. (2001). Henri Lefebvre 1901-1991. Available from http://www.ualberta.ca/~rshields/f/lefebvre.htm

Shin, N., Jonassen, D. H., & McGee, S. (2003). Predictors of well-structured and ill-structured problem solving in an astronomy simulation. *Journal of Research in Science Teaching, 40*(1), 6-33.

Sjöström, B., & Dahlgren, L. O. (2002). Applying phenomenography in nursing research. *Journal of Advanced Nursing, 40*(3), 339-345.

Soja, E. W. (1989). Postmodern geographies: The reassertion of space in critical social theory. London: Verso.

Soja, E. W. (2003). Postmodern geographies: The reassertion of space in critical social theory. New York: Verso.

Spinks, N., Silburn, N., & Birchall, D. (2006). Educating engineers for the 21st century: The industry view. *London: The Royal Academy of Engineering*.

Srivastava, A., & Yammiyavar, P. (2018). Exploring embedded intelligence as a means of minimizing cognitive load of students in electronics engineering instructional laboratory sessions. In G. G. Ray, R. Tqbal, A. K. Ganguli, & V. Khanzode, *Ergonomics in Caring for People* (pp. 261-266). Singapore: Springer.

Tafur, M., Evangelou, D., & Strobel, J. (2012). *Troubleshooting skills for non-engineers in technological jobs.* Paper presented at the American Society for Engineering Education. San Antonio, Texas.

Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences.* Thousand Oaks, CA: Sage.

Teddlie, C., & Yu, F. (2007). Mixed methods sampling: A typology with examples. *Journal of Mixed Methods Research, 1*(1), 77-100.

Thrift, N. (1999). Steps to an ecology of place. *Human Geography Today.* Proceedings of the General Meeting of the Association of Japanese Geographers (59), 295-322. New York.

Tight, M. (2016). Phenomenography: The development and application of an innovative research design in higher education research. *International Journal of Social Research Methodology, 19*(3), 319-338.

Trevelyan, J. (2007). Technical coordination in engineering practice. *Journal of Engineering Education, 96*(3), 191-204.

Troubleshoot. (n.d). in English Oxford Living Dictionaries. Retrieved from https://en.oxforddictionaries.com/definition/troubleshoot.

Tuan, Y.-F. (1979). Space and place: humanistic perspective. In S. Gale & G. Olsson (Eds.), *Philosophy in geography* (pp. 387-427). Dordrecht: Springer.

Van De Bogart, K. L. (2017). Investigating student learning of analog electronics. Electronic Theses and Dissertations. 2660. http://digitalcommons.library.umaine.edu/etd/2660. Retrieved 28 July 2018.

Van De Bogart, K. L., Dounas-Frazer, D. R., Lewandowski, H. J., & Stetzer, M. R. (2015). The role of metacognition in troubleshooting: An example from electronics. *arXiv preprint arXiv:1507.03941*.

Van der Bijl, A., & Taylor, V. (2016). Nature and dynamics of industry-based workplace learning for South African TVET lecturers. *Industry and Higher Education, 30*(2), 98-108.

Van Gog, T., Paas, F., & Van Merriënboer, J. J. (2006). Effects of process-oriented worked examples on troubleshooting transfer performance. *Learning and Instruction, 16*(2), 154-164.

Van Gog, T., Paas, F., & Van Merriënboer, J. J. (2008). Effects of studying sequences of process-oriented and product-oriented worked examples on troubleshooting transfer efficiency. *Learning and Instruction, 18*(3), 211-222.

Van Hentenryck, P., & Coffrin, C. (2015). Transmission system repair and restoration. *Mathematical Programming, 151*(1), 347-373.

Vigil, A., Miller, R. L., & Sloan Jr, E. D. (n.d.). Structured Troubleshooting in Process Design. *age, 4,* 1.

Weaver, R. B. (2013). *The neolithic of the Peak District: a Lefebvrian social geography approach to spatial analysis.*

APPENDIX A - INTERVIEW PROTOCOLS

FOR LECTURERS

BIOGRAPHICAL INFORMATION

Gender		
Qualification (What engineering degrees, diploma or certificate you have earned?)		
Date obtained		
If employed in the industry before, please answer the following questions:		
	What department/unit/section	
	Numbers of years employed	
	Capacity in which employed	
If employed in teaching/training of engineers, please answer the following questions:		
	What department/unit/section have you taught/teaching?	
	Numbers of years employed	
	Capacity in which employed	
	Courses taught/teaching currently	

Student's training/project supervision experience

Q1. Which aspect of problem solving tasks have you taught electronics engineering students before?
- i. *Can you please give examples?*
- ii. *Which of these problem-solving tasks do you consider more important for present day engineering training?*

Q2. What were the types of troubleshooting related content you have taught electronics engineering students before?
- i. *Was any model used to teach the content?*
- ii. *If yes, which model have you used?*

Q3. Were the students given any specific troubleshooting tasks in their training?
- i. *What type of troubleshooting task were they given?*
- ii. *What was the objective of the task?*
- iii. *Did the task require design, production or maintenance/repair?*

Q4. What was the place of electronics troubleshooting in the training given to the students?
- i. *Required for practice?*
- ii. *Required for conceptual understanding?*
- iii. *Required for supervisory purpose in industry?*

Q5. Do you have specific equipment/instruments for training electronics engineering students to acquire troubleshooting skills?

a) If yes, which ones do you use/recommend in your practice?

I. *How relevant are such equipment to current electronics technology?*

II. *Are they adequate for training students? If yes/no please elaborate.*

b) If not, what are your thoughts on the use of specific equipment/instruments for training electronics engineering students to acquire troubleshooting skills?

Q6. How do you determine the engineering troubleshooting skills acquired by students to meet industry's standard?

i. *Please elaborate.*

Q7. Why do you give the kind of tasks you assign the students?

LABORATORY TECHNICIANNS

Gender		
Qualification (What engineering degrees, diploma or certificate you have earned?)		
Date obtained		
If employed in the industry before, please answer the following questions:		
	What department/unit/section	
	Numbers of years employed	
	Capacity in which employed	
If employed in teaching/training of engineers, please answer the following questions:		
	What department/unit/section have you taught/teaching?	
	Numbers of years employed	
	Capacity in which employed	
	Courses taught/teaching currently	

Student's training/project supervision experience

Q1. Which aspect of problem solving tasks have you taught electronics engineering students before?

I. *Can you please give examples?*

II. *Which of these problem-solving tasks do you consider more important for present day engineering training?*

Q2. What were the types of troubleshooting related content you have taught electronics engineering students before?

i. *Was any model used to teach the content?*

ii. *If yes, which model have you used?*

Q3. Were the students given any specific troubleshooting tasks in their training?

i) *What type of troubleshooting task were they given?*

ii) *What was the objective of the task?*

iii) *Did the task require design, production or maintenance/repair?*

Q4. What was the place of electronics troubleshooting in the training given to the students?

i) *Required for practice?*

ii) Required for conceptual understanding?
iii) Required for supervisory purpose in industry?

Q5. Do you have specific equipment/instruments for training electronics engineering students to acquire troubleshooting skills?

a) If yes, which ones do you use/recommend in your practice?
i) *How relevant are such equipment to current electronics technology?*
ii) *Are they adequate for training students? If yes/no please elaborate.*
b) If not, what are your thoughts on the use of specific equipment/instruments for training electronics engineering students to acquire troubleshooting skills?

Q6. How do you determine the engineering troubleshooting skills acquired by students to meet industry's standard?
ii. *Please elaborate.*

Q7. Why do you conduct engineering tasks assigned to students in the way you do during laboratory practices?

ECSA MEMBERS

BIOGRAPHICAL INFORMATION

Gender		
Qualification (What engineering degrees, diploma or certificate you have earned?)		
Date obtained		
If employed in the industry, please answer the following questions:		
	What department/unit/section	
	Numbers of years employed	
	Capacity in which employed	
If employed in teaching/training of engineers, please answer the following questions:		
	What department/unit/section have you taught?	
	Numbers of years employed	
	Capacity in which employed	
	Courses taught/teaching currently	

Training /Exit Level Outcome Information

Q1. What do you perceive as the main objectives of engineering training for workplace practice?

Q2. What are the workplace exit level outcomes expected by the council for electronics engineers?

Q3. What are your general requirements and expectations for students who engage in electronics engineering tasks? (Do the engineering tasks expected of students require the design of a new product, procedure, model or system?)
i. If so, please elaborate?

ii. *If not, what are your requirements and expectations for students who engage in electronics engineering tasks?*

Q4. Do the engineering tasks expected of students require electronics troubleshooting skills of industry-based systems and other electronics devices?

i. *If so, please elaborate?*
ii. *If not, what are your expectations?*

Q5. Is there a place for electronics troubleshooting for undergraduates engineering students in ECSA's standard for the members?

i. *If so what (where and how) is the place of electronics troubleshooting for undergraduates engineering students in ECSA's standard for the members?*
ii. *If not, why?*

FOURTH-YEAR ELECTRONICS ENGINEERING STUDENTS

BIOGRAPHICAL INFORMATION

Age	
Gender	
Specialization	
Year of study	
Area of interest in practical project	
What is the motivation behind the area of your interest?	
Stage of your project	Just began ☐ Middle way ☐ Near completion ☐ Completed ☐

Interview protocol

Q1. In your own words, what is your understanding about engineering – more particularly about electronics engineering?

Q2. Are there particular skills that you would say are important for an engineer/electronics engineer to have?

i. *Of the skills that you mentioned, which ones do you think are most important? Rate them*

----

ii. *Of the skills that you mentioned, which ones of these do you think you possess? And why?*

iii. *How did you develop these skill(s)?*

iv. *Now, I want to single out one particular skill, that is Troubleshooting, what do you understand by the term Troubleshooting?* (SAY "Just whatever it means to you – anything that comes to your mind")

Q3. Have you had any experience(s) inside or outside of your classes/laboratory that have enabled you to troubleshoot electronics equipment or systems?

i. *If yes, please describe the experience.*

(a) Can you rate your troubleshooting ability in engineering training?

{On a scale from 0 – 10, (where 0 = not confident at all and 10 = extremely confident), how confident are you in your troubleshooting ability?}

(b) Can you describe the experiences that led you to rate yourself in this way?

ii. *If not, have you done so theoretically?*

FOCUSED GROUP INTERVIEW PROTOCOL (STUDENTS)

Q1 Have you experienced any fault, failure or problems in the design from the start up point to the completion of the project (implementation)?
Please elaborate.

Q2 How did you solve the problem? I mean did you carry out any troubleshooting task on the circuit, system or product to resolve the problem?

Q3 How did you develop the skill to solve the problem? (Where and when did you develop the skill?)

Q4 Considering the solutions you have given to emergent problems in the course of design and implementation of this project, can you tell me the reason(s) for applying the troubleshooting approach in solving the problems encountered in the course of the design?

APPENDIX B – INFORMED CONSENT LETTERS

INFORMED CONSENT LETTER (STUDENTS)

My name is **Jonathan Fatokun.** I am a Science and Technology Education Ph.D candidate studying at the University of KwaZulu-Natal, Edgewood campus, South Africa.
I am interested in exploring the place of troubleshooting within electronics engineering programme in order to determine the kind of troubleshooting skills that are expected from electronics engineering students at the University of KwaZulu-Natal, South Africa. To gather the information, I am interested in asking you some questions about the requisite troubleshooting skills that are expected from electronics engineering students who are now engaged in their final year practical projects.

Please note that:

- The research aims to explore the place of troubleshooting within electronics engineering education programme in order to determine the kind of troubleshooting skills that are expected from fourth year students who are working on their projects as perceived by **the students**.
- Your confidentiality is guaranteed as your inputs will not be attributed to you in person, but reported only as a community population member's opinion.
- If you are interviewed, the interview may last for approximately an hour and may be split depending on your preference.
- If you are participating in the study as a learner, or trainer, you may be asked questions, or asked to give your opinions, as part of a group meeting which may take up to 2 hours.
- Any information given by you cannot be used against you, and the collected data will be used for purposes of this research only.
- Data will be stored in secure storage in the Department of Science and Technology, School of Education, Edgewood campus, University of KwaZulu Natal and destroyed after 5 years.
- You have a choice to participate, not participate or stop participating in the research. You will not be penalized for taking such an action.
- Your involvement is purely for academic purposes only, and there are no financial benefits involved.
- You may be asked to take part in a telephonic interview, or interview via online teleconferencing (e.g. Skype), if so, you will be given a copy of the questions to study in advance of the interview should you desire this.
- If you are willing to be interviewed, please indicate (by ticking as applicable) whether or not you are willing to allow the interview to be recorded using the following equipment:

Recording equipment to be used in the study	I am willing	I am not willing
Audio equipment		
Photographic equipment		
Video equipment		

If you wish to discuss this further with me or wish to understand more about the research study, I can be contacted at:

Jonathan Fatokun
Department of Science and Technology, School of Education, Edgewood campus, University of KwaZulu Natal.

Cell: +27 (0)83 9841 035 Email: jofatokun@gmail.com

My supervisor is **Dr. Busisiwe Alant**
Department of Science and Technology, School of Education, Edgewood campus, University of KwaZulu Natal.
Tel: +27 (0)312607606 Cell: +27 (0)739479893 Email: Alantb@ukzn.ac.za

You may also contact the **Research Office** through:
P. Mohun
HSSREC Research Office,
Tel: 031 260 4557/4609Email: HssrecHumanities@ukzn.ac.zaE-mail: mohunp@ukzn.ac.za

Thank you for your contribution to this research.

DECLARATION

I……………………………………………………………………… (full name of participant) hereby confirm that I understand the contents of this document and the nature of the research project, and I consent to participating in the research project. I understand that I am at liberty to withdraw from the project at any time, should I so desire.

SIGNATURE OF PARTICIPANT **DATE**

………………………………………… ……………………………………

FULL NAME AND SURNAME OF PARTICIPANT (PLEASE PRINT)

………………………………………………………………………………………..

Dear Mr/Dr/Prof.,

INFORMED CONSENT LETTER (LECTURERS)

My name is **Jonathan Fatokun.** I am a Science and Technology Education Ph.D candidate studying at the University of KwaZulu-Natal, Edgewood campus, South Africa.
I am interested in exploring the place of troubleshooting within electronics engineering programme in order to determine the kind of troubleshooting skills that are expected from electronics engineering students at the University of KwaZulu-Natal, South Africa. To gather the information, I am interested in asking you some questions about the requisite troubleshooting skills that are expected from electronics engineering students who are engaged in their final year practical projects.

Please note that:

- The research aims to explore the place of troubleshooting within electronics engineering education programme in order to determine the kind of troubleshooting skills that are expected from fourth year students who are working on their projects as perceived by the lecturers.
- Your confidentiality is guaranteed as your inputs will not be attributed to you in person but reported only as a community population member's opinion.
- If you are interviewed, the interview may last for approximately an hour and may be split depending on your preference.
- If you are participating in the study as a learner, or trainer, you may be asked questions, or asked to give your opinions, as part of a group meeting which may take up to 2 hours.
- Any information given by you cannot be used against you, and the collected data will be used for purposes of this research only.
- Data will be stored in secure storage in the Department of Science and Technology, School of Education, Edgewood campus, University of KwaZulu Natal and destroyed after 5 years.
- You have a choice to participate, not participate or stop participating in the research. You will not be penalized for taking such an action.
- Your involvement is purely for academic purposes only, and there are no financial benefits involved.
- You may be asked to take part in a telephonic interview, or interview via online teleconferencing (e.g. Skype), if so, you will be given a copy of the questions to study in advance of the interview should you desire this.

If you wish to discuss this further with me or wish to understand more about the research study, I can be contacted at:

Jonathan Fatokun
Department of Science and Technology, School of Education, Edgewood campus,University of KwaZuluNatal.
Cell: +27 (0)83 9841 035 Email: jofatokun@gmail.com

My supervisor is **Dr. BusisiweAlant**
Department of Science and Technology, School of Education, Edgewood campus,University of KwaZuluNatal.
Tel: +27 (0)312607606 Cell: +27 (0)739479893 Email: Alantb@ukzn.ac.za

You may also contact the **Research Office** through:
P. Mohun
HSSREC Research Office,
Tel: 031 260 4557/4609Email: HssrecHumanities@ukzn.ac.zaE-mail: mohunp@ukzn.ac.za

Thank you for your contribution to this research.

DECLARATION

I……………………………………………………………………………… (full name of participant) hereby confirm that I understand the contents of this document and the nature of the research project, and I consent to participating in the research project.I understand that I am at liberty to withdraw from the project at any time, should I so desire.

SIGNATURE OF PARTICIPANT DATE

……………………………………… ………………………………….

FULL NAME AND SURNAME OF PARTICIPANT (PLEASE PRINT)

……………………………………………………………………………………..

Dear Mr/Dr/Prof.,

INFORMED CONSENT LETTER (TECHNICIANS)

My name is **Jonathan Fatokun.** I am a Science and Technology Education Ph.D candidate studying at the University of KwaZulu-Natal, Edgewood campus, South Africa.
I am interested in exploring the place of troubleshooting within electronics engineering programme in order to determine the kind of troubleshooting skills that are expected from electronics engineering students at the University of KwaZulu-Natal, South Africa. To gather the information, I am interested in asking you some questions about the requisite troubleshooting skills that are expected from electronics engineering students who are engaged in their final year practical projects.

Please note that:

- The research aims to explore the place of troubleshooting within electronics engineering education programme in order to determine the kind of troubleshooting skills that are expected from fourth year students who are working on their projects as perceived by **the laboratory technicians**.
- Your confidentiality is guaranteed as your inputs will not be attributed to you in person, but reported only as a community population member's opinion.
- If you are interviewed, the interview may last for approximately an hour and may be split depending on your preference.
- If you are participating in the study as a learner, or trainer, you may be asked questions, or asked to give your opinions, as part of a group meeting which may take up to 2 hours.
- Any information given by you cannot be used against you, and the collected data will be used for purposes of this research only.
- Data will be stored in secure storage in the Department of Science and Technology, School of Education, Edgewood campus, University of KwaZulu Natal and destroyed after 5 years.
- You have a choice to participate, not participate or stop participating in the research. You will not be penalized for taking such an action.
- Your involvement is purely for academic purposes only, and there are no financial benefits involved.
- You may be asked to take part in a telephonic interview, or interview via online teleconferencing (e.g. Skype), if so, you will be given a copy of the questions to study in advance of the interview should you desire this.

If you wish to discuss this further with me or wish to understand more about the research study, I can be contacted at:

Jonathan Fatokun
Department of Science and Technology, School of Education, Edgewood campus,University of KwaZuluNatal.
Cell: +27 (0)83 9841 035 Email: jofatokun@gmail.com

My supervisor is **Dr. BusisiweAlant**
Department of Science and Technology, School of Education, Edgewood campus,University of KwaZuluNatal.
Tel: +27 (0)312607606 Cell: +27 (0)739479893 Email: Alantb@ukzn.ac.za

You may also contact the **Research Office** through:
P. Mohun
HSSREC Research Office,

Tel: 031 260 4557/4609Email: HssrecHumanities@ukzn.ac.zaE-mail: mohunp@ukzn.ac.za

Thank you for your contribution to this research.

DECLARATION

I………………………………………………………………………… (full name of participant) hereby confirm that I understand the contents of this document and the nature of the research project, and I consent to participating in the research project.I understand that I am at liberty to withdraw from the project at any time, should I so desire.

SIGNATURE OF PARTICIPANT DATE

………………………………………… …………………………………

FULL NAME AND SURNAME OF PARTICIPANT (PLEASE PRINT)

…………………………………………………………………………………..

Dear Mr/Dr/Prof.,

INFORMED CONSENT LETTER (ECSA MEMBER)

My name is **Jonathan Fatokun.** I am a Science and Technology EducationPh.Dcandidate studying at the University of KwaZulu-Natal, Edgewood campus, South Africa.
I am interested in exploring the place of troubleshooting within electronics engineering programme in order to determine the kind of troubleshooting skills that are expected from electronics engineering students at the University of KwaZulu-Natal, South Africa. To gather the information, I am interested in asking you some questions about the requisite troubleshooting skills that are expected from electronics engineering students who are engaged in their final year practical projects.

Please note that:

- The research aims to explore the place of troubleshooting within electronics engineering education programme in order to determine the kind of troubleshooting skills that are expected from final year students who are working on their projects as perceived by the lecturers who are **members of Engineering Council of South Africa (ECSA)**.
- Your confidentiality is guaranteed as your inputs will not be attributed to you in person, but reported only as a community population member's opinion.
- If you are interviewed, the interview may last for approximately an hour and may be split depending on your preference.
- If you are participating in the study as a learner, or trainer, you may be asked questions, or asked to give your opinions, as part of a group meeting which may take up to 2 hours.
- Any information given by you cannot be used against you, and the collected data will be used for purposes of this research only.
- Data will be stored in secure storage in the Department of Science and Technology, School of Education, Edgewood campus, University of KwaZulu Natal and destroyed after 5 years.
- You have a choice to participate, not participate or stop participating in the research. You will not be penalized for taking such an action.
- Your involvement is purely for academic purposes only, and there are no financial benefits involved.
- You may be asked to take part in a telephonic interview, or interview via online teleconferencing (e.g. Skype), if so, you will be given a copy of the questions to study in advance of the interview should you desire this.

If you wish to discuss this further with me or wish to understand more about the research study, I can be contacted at:

Jonathan Fatokun
Department of Science and Technology, School of Education, Edgewood campus,University of KwaZuluNatal.
Cell: +27 (0)83 9841 035 Email: jofatokun@gmail.com

My supervisor is **Dr. BusisiweAlant**
Department of Science and Technology, School of Education, Edgewood campus,University of KwaZuluNatal.
Tel: +27 (0)312607606 Cell: +27 (0)739479893 Email: Alantb@ukzn.ac.za

You may also contact the **Research Office** through:
P. Mohun
HSSREC Research Office,
Tel: 031 260 4557/4609Email: HssrecHumanities@ukzn.ac.zaE-mail: mohunp@ukzn.ac.za

Thank you for your contribution to this research.

DECLARATION

I……………………………………………………………………………… (full name of participant) hereby confirm that I understand the contents of this document and the nature of the research project, and I consent to participating in the research project.I understand that I am at liberty to withdraw from the project at any time, should I so desire.

SIGNATURE OF PARTICIPANT DATE

……………………………………… ………………………………….

FULL NAME AND SURNAME OF PARTICIPANT (PLEASE PRINT)

………………………………………………………………………………..

APPENDIX C - EDITOR'S CERTIFICATE

Crispin Hemson
15 Morris Place
Glenwood
Durban
South Africa 4001

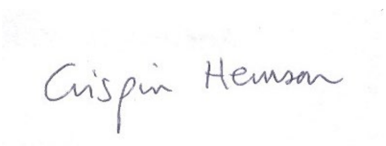
hemsonc@gmail.com
C: 082 926 5333
H: 031 206 1738

13th August 2018

TO WHOM IT MAY CONCERN

This is to record that I have carried out a full language editing of a thesis by Jonathan Olanrewaju Fatokun entitled: E**xploring the place of troubleshooting in an undergraduate electronics engineering education programme at a university in South Africa.**

Yours sincerely



Crispin Hemson

APPENDIX D - TURN IT IN REPORT

Turnitin *Originality Report*

- Processed on: 13-Aug-2018 9:21 PM CAT
- ID: 989709123
- Word Count: 59443
- Submitted: 1

EXPLORING THE PLACE OF TROUBLESHOOTING IN AN ... *By Jonathan Fatokun*

Similarity Index
12%
Similarity by Source
Internet Sources:
10%
Publications:
7%
Student Papers:
5%

exclude quoted exclude bibliography exclude small matches download refresh print

mode: quickview (classic) report

APPENDIX E: SUMMARY OF FINDINGS

SUMMARY OF FINDINGS ON THE PLACE OF TROUBLESHOOTING IN THE ELECTRONICS ENGINEERING PROGRAMME													
RQ1	**Council on Higher Education**		**Electronics Handbook**		**Electronics Lecturers (3)**		**Laboratory instructors (2)**		**Engineering Council of South Africa - ECSA (1)**		**4th year EE Students (6)**		**Outcome space**
Is TS accommodated in EEP	**Y**	**N**	**Y**	**N**	**Y**	**N**	**Y**	**N**	**Y**	**N**	**Y**	**N**	
#		**1**		1	**2**	**1**	**0**	**2**	**0**	**1**	**6**	**0**	
%		**100%**		100%	**67%**	**33%**	**0**	**100%**	**0**	**100%**	**100%**		
If so, what is being foregrounded?	Focus is on Design				Unique Approach - teaches students how to think						The intutive nature of TS		The Approach
					Time - *vis-a-vis* curriculum delivery						Design skills taught from 1st year to 4th year		In Curriculum delivery
					Design - as the context for problem solving						Context - embedded in Design		Troubleshooting in Design
											Context - embedded in design projects (Evaluation/testing)		
											Context of TS - embedded in programming		

											Context - embedded in debugging of software		
How?					Approach - instills creativity								
					Time - structures project completion								
					Design - identifying design problems								
If not, what is being foregrounded?		Competency in solving complex problem		Courses on Problem solving skills		Engineering practicals				Ability to solve complex eng problems			Solving Complex Engineering problems
		Competency in design skill		Courses on Engineering design		Scope of engineering jobs (design)		Engineering design		Ability to design			Design
						Organic troubleshooting							Organic troubleshooting
How?		Engineering design - performing procedural and non-procedural design		Engineering design skills - Applying Scientific and enquiring mind		Engineering practicals - by having practicals frequently		Engineering design - by applying scientific and enquiring mind		Engineering graduate skills - through the understanding of the pillars of engineering			

		Problem solving- Identify, analyse and solve complex engineering problems		Problem solving skills - solving complex engineering problems		Organic troubleshooting - through the top-down approach				Eleven exit level outcomes - by acquiring engineering knowledge and skills			
		Application of Scientific and Engineering Knowledge to solve complex engineering problems				Scope of engineering jobs - by designing and simulating							
RQ2				Through the courses listed below:									
How is EEP being enacted?				Electronic Design Project	Reinforcement						Troubleshooting strategy/Personal experience		Individual-based practice
				Electronics design 1 & 2	Written examination								Theory-based practice
				Electronics design 3	Problem based learning	Systematic approach					Solving Programming problem in design		Design-based practice
				Vacation Work	Serial/Systematic check/testing	Competency test in design							
					Practical laboratory and design tasks	Engineering tasks (Lab and design)		Engineering tasks (Lab and design)					
RQ3							LECTURER/ TECHNICIAN				STUDENTS		

					The objective of engineering programme	Engineering programme's learning outcome		Engineering Learning Outcome			Troubleshooting is personal		
What informs what is being enacted?					Paraprofessional difference	The Curriculum specification		Engineering Programme Curriculum			Intuition and research		
											Troubleshooting requires experiential knowledge		