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Mathematics for Future Engineers: A Study of Teaching and Learning Mathematics in an Engineering Curriculum

By

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ABSTRACT

This is a study of teaching and learning in the first mathematics module for engineering students at a South African university. The theoretical framing of the study is derived from multiple analytical tools: Bernstein's theory of the Pedagogic Device; the construct of beliefs and Bloom's revised taxonomy. As such this study draws on Bernstein's concepts of recontextualisation, singulars and regions and classification and framing to describe the three message systems (content, pedagogy and assessments). The beliefs framework identifies the teaching styles used by lecturers while Bloom's revised taxonomy provides the analytical tool to evaluate the quality of the final examination questions.

This study took a pragmatist stance which privileged a mixed methods approach to data collection. The first research question sought to determine the role of mathematics in engineering. To fully understand the role of mathematics in engineering, document analysis was used to analyse the international (Washington Accord) and national (ECSA) professional body documents and the institutional requirements and interviews were conducted with academic staff in the department of mathematics and the school of engineering. The literature showed that mathematics is a key component in engineering education and in engineering practice. It also foregrounded the ongoing debate about whether it is sufficient for engineers to know the practical application of mathematics or whether knowledge of mathematics in all its abstraction is required.

The second and third research questions looked at how teaching and learning is approached and reasons why it is approached in those ways. Data were generated from the documents stated above, observation of lectures as well as tutorials and interviews with relevant academic staff and students. An analysis of the Washington Accord and ECSA documents fell within the Official Recontextualising Field and showed the influence of the external bodies on the recontextualisation of the ME curriculum. The textbook and head of school (MSC), constituted the Pedagogic Recontextualising Field (PRF), and were found to influence the framing over selection, sequencing, pacing and evaluative criteria. It was also established that there was further recontextualisation at the level of the classroom (by lecturers). In effect, the recontextualisation resulted in the exclusion of proofs and theoretical underpinning of the mathematics taught. The module showed strong classification of content on the interdisciplinary, intradisciplinary and interdiscursive level while framing over selection, sequencing, pacing and evaluative criteria were strong. The regionalization of the ME module resulted in it being a site of conflict and struggle over ownership of the pedagogic device.

Despite differences in beliefs about mathematics, the teaching styles of lecturers were similar in that they demonstrated an algorithmic, assessment-oriented approach to teaching. The analysis revealed that lecturers viewed mathematics in terms of application and as a tool to solve engineering problems. Analysis of the final examination questions showed that it fell within the cognitive domain of *Apply* in Blooms' revised taxonomy. A closer inspection of the final examination questions and those of the mock examination showed a close correlation between the two indicating that the conceptual demand was not as high as initially established. Despite the strong alignment between lectures, tutorials and assessments, many students were unsuccessful in passing the module.

The thesis concludes with a discussion of the implications of the findings and suggests recommendations for the improvement of teaching and learning mathematics to future engineers and for further research.

DECLARATION

I, Mogasuri Moodley, 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 referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced.

(v) The work described in this thesis was carried out in the School of Engineering, University of KwaZulu-Natal, from February 2011 to January 2014 under the supervision of Dr Sally Hobden (Supervisor)

(vi) The Ethical clearance (No. HSS/0935/011D) was granted prior to undertaking the fieldwork.

Signed:

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As the candidate's Supervisor I, Sally Hobden, agree to the submission of this thesis.

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This dissertation has been realised due to the support of many individuals. It is with pleasure and gratitude that I acknowledge their efforts.

The lecturers in the ME module, the first year engineering students, and tutors for their willing participation who gave off their time to participate in this study without immediate benefit to themselves.

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List of Acronyms

ABET	Accreditation Board for Engineering and Technology
AMSI	Australian Mathematical Sciences Institute
ATN	Australian Technology Network of Universities
B.Ed (Hons)	Bachelor of Education Honours degree
CBM	Computer-based methods
CoAES	College of Agriculture, Engineering and Science
DoE	Department of Education
HEI	Higher Education Institution
HoS	Head of school
IMA	Institute of Mathematics and its Application
ME	Mathematics for Engineers
MSC	Mathematics, Statistics and Computer Science
MWG	Mathematics Working Group NPHE National Plan for Higher Education
NSC	National Senior Certificate
NSF	National Science Foundation
OBE	Outomes Based Education
ORF	Official Recontextualising Field
PBL	Problem Based Learning
PRF	Pedagogic Recontextualising Field
SAHEI	The South African Higher Education Institution in this study
SEFI	European Society for Engineering Education
UK	United Kingdom
UNISA	University of South Africa
USA	United States of America

Chapter One
Introduction

The purpose of this study is to explore teaching and learning in the first mathematics module, Mathematics for Engineers (ME), studied by engineering students in the engineering curriculum at a South African Higher Education Institution (SAHEI). This study delves into the curriculum which includes the content, lectures, tutorials and assessments to thoroughly explore how teaching and learning the ME module is approached at this institution. People who are writing in the field of engineering education have undertaken to improve teaching and learning and are using approaches different from the traditional methods of teaching. They acknowledge that traditional lecture-style teaching is still rife and make the assumption that those still engaging in traditional teaching practice are not engaged in research in engineering, or mathematics education. At this SAHEI little research has been done in engineering education and, more specifically, even less on the mathematical education of engineering students. Therefore this research has much to offer the institution in terms of how the mathematical education of engineering students is approached nationally and internationally.

1.1 Motivation for the Study

My interest in teaching and learning in the ME module is a culmination of a number of interrelated events. In the first instance, it is informed by my own experiences as a high school and university student, secondly as an educator of mathematics for nearly two decades, thirdly as a postgraduate student in the field of mathematics education, fourthly as a lecturer in Mathematics Education modules (to in-service teachers and postgraduate students) and finally in my post as an academic development coordinator in the Faculty of Engineering. These experiences have helped shape this study. Of particular note is how I often tried to make mathematics accessible to all students believing then, as I do now, that mathematics is a 'purely human endeavour'. My experiences of high school mathematics were positive and vastly different to my experiences of it in higher education. As a mathematics educator, I found it difficult to accept my colleagues' school of thought, which was to strictly follow the work schedule and to continue with the syllabus as prescribed for all classes (strong framing) because I believed that every learner should understand the concepts before the next topic was introduced. My attempts at designing a mathematics game, as part of my B.Ed (Honours), to facilitate the learning of integers in mathematics in a way that engaged students and made mathematics enjoyable, proved to be a good learning experience for me and tempered my idealism. Learners showed greater enjoyment of those lessons compared with normal lessons but the findings of my study showed that this did not result in improved performance in mathematics. For many educators, having their learners perform well is important in many ways: it elevates their sense of pride and self-worth and establishes them as good educators in the eyes of their peers and the wider community.

Following this work, my Master's dissertation, which focused on identifying the challenges that learners face in the mathematics class, revealed that teachers play a significant role in the development of learners' beliefs in their capability to do mathematics. Subsequently, I have been involved in lecturing in mathematics education, the focus being on theories of teaching and learning mathematics and their applications in educational contexts. These have been positive learning experiences allowing me to develop as a student, a researcher and an educator. My subsequent role in academic development in the School of Engineering, and subsequently in the School of Mathematics has brought me in close contact with future engineers (some of them my former students) for whom mathematics is a core module in engineering. From my experiences of working with students who perform below the university norm I have found that while students may have gained physical access into engineering success seem to be out of reach of many of them.

South Africa currently faces a dearth of qualified engineers (Lawless, 2005) a situation that has been described as "one of the worst capacity and scarce-skills crises" (du Toit & Roodt, 2009, p. 11). In comparison with other countries, South Africa has 473 engineers to every one million of its population, while Japan has 3306 and Malaysia 1843 (du Toit & Roodt, 2009). The national skills shortage is seen as the product of poor education and training and attributed to the inferior quality of schooling provided to Black learners. In addition, the decline in National Senior Certificate (NSC) performance in mathematics and science between 1991 and 2006, as reported by the Centre for Development and Enterprise, has been blamed on poor schooling (Rasool & Botha, 2011). Historically, the apartheid education system in pre-democracy South Africa, refused access to Black South Africans to quality education thus depriving them of equal educational opportunities. Minimal funding was allocated to Black education with the result that the quality of education was poor. The effect was particularly marked in mathematics and science. In post-apartheid South Africa the historical imbalances still control the economic divide in society that is reflected in the current education system. In reality, poverty and wealth are determinants of how formal education is distributed since middle and upper class students are more likely to have greater chances of success than lower class students (Bernstein, 2000). The devastating effect that apartheid policies had on Black South Africans was mirrored in the negative impact on economic and social development in the country. This made the pursuit of professional careers in mathematics and science-related fields for Black learners very difficult.

In order to gain a full understanding of South African higher education and how it affects students' learning, I provide a brief overview of the historical background of the restructured higher education system. The National Plan for Higher Education (NPHE), released in March 2001, noted the low average graduation rates (15%) as well as the duplication of efforts among universities, historically segregated along racial lines (Department of Education, 2001). The low graduation rates together with the structure of higher education, seen as ineffective, formed the justification for the reform and desegregation of South African Higher Education Institutions. This allowed access to students from all backgrounds resulting in a radically different and diverse composition of students (Jama, Mapesela, & Beylefeld, 2008; Jansen, 2009). The following two decades, saw radical changes in student numbers and student profiles with regard to cultural capital, socio-economic and educational backgrounds and mathematical competencies. While the student composition is no longer racially defined the staff composition, predominantly white, has changed little. Seven of the eight universities offering engineering and seven technikons, now called Universities of Technology had been reserved for the white community only. The new democracy opened up these previously 'whites only' universities and technikons to students of colour (Case & Jawitz, 2003). The South African Higher Education Institution (SAHEI) in this study was an outcome of the merger between several institutions of higher education, in a bid to reduce the inequalities between previously Black and White institutions.

The influx of students from disadvantaged backgrounds into higher education and more specifically engineering, initiated several interventions perceived to be necessary, academic development being one of them. Academic development brought with it a different way of thinking about teaching and learning and led to the recruitment of staff with educational expertise. This led to expertise in teaching and learning approaches and curriculum development relevant to South African engineering education. The Engineering Council of South Africa (ECSA), the statutory body accrediting engineering programmes, and a signatory to the Washington Accord changed to an outcomes-based system in 1998. This was in keeping with trends amongst international accrediting bodies and in alignment with the new South African National Qualifications Framework (NQF). Case & Jawitz (2003) acknowledge that discipline experts and academic development practitioners are in constant collaboration to enhance engineering education by focusing on effective teaching approaches catering for a diverse student population and aligned to an outcomes-based curriculum. While access to South African higher education for students from disadvantaged backgrounds has improved, the attrition rates are high (Letseka & Maile, 2008). The recent report from the Council on Higher Education (CHE) (Ndebele, Badsha & Figaji, 2013) states that from the 2006 first-time entering cohort, 23% of African students, 41% of coloured students, 37% of Indian students and 55% of white students graduated with engineering degrees within five years.

In the recent years, in response to the critical shortage of engineering professionals, the directive from the National Department of Higher Education, based on the report from the National Commission on Higher Education, resulted in South African universities widening access into engineering (NCHE report, 1996). One of the government imperatives is highlighted in the White Paper 3 on Higher Education Transformation (Department of Education, 1997a) and calls for the improvement of throughput rates in higher education. In response, the South African National Plan on Higher Education (Department of Education, 2001) and the South African Higher Education Act (Department of Education, 1997b) supported this with a call to enhance the quality of teaching and learning strategies in higher education and made funding available to encourage re-conceptualising the teaching and learning paradigms in support of this.

Industry response to the call for more, qualified engineers has been successful in that large companies have made bursaries available for the study of engineering in order to increase the number of engineers, making engineering a choice for students who otherwise might not be able to afford to study at university. Hence, the demand to study engineering is high and this results in a large number of students applying for acceptance into engineering. For reasons, both academic and financial, the number of places within each discipline of engineering is limited. Despite the fact that students are carefully selected on the basis of their mathematics and physical science marks, the pass rates in mathematics have been consistently poor with the retention and graduation rates of engineering students being particularly low. As a pipe-line, the faculty of engineering at this university is still not producing engineers in sufficient numbers to adequately address the critical shortage in South Africa. Declining enrollment into engineering has been a matter of concern globally as indicated by the Australian Technology Network of Universities (ATN) (2007) and Kent and Noss (2003) but this is not the case in South Africa. South Africa has been experiencing a shortage of engineers but this is not due to a decline in engineering enrollment, but rather attributed to the low graduation rates of engineers. In addition a common concern internationally and in South Africa is the low number of engineering students who pass mathematics (Bringslid, 2002). I believe this is an indication that the mathematics education of engineering students is a matter of concern and is in need of investigation.

1.2 Research Questions and Focus

Since 2008 South African students entering engineering for the first time have been educated predominantly through a curriculum underpinned by outcomes-based education (OBE) (Engelbrecht, Harding & Phiri, 2009). It has been found that the shift to a learner-centered approach from a focus on the three ‘Rs’, reading, writing and arithmetic, has resulted in learners who grapple with reading and the level of understanding required of university students entering SAHEIs (Mouton, Louw & Strydom, 2012). Higher education pass rates have been low (Case, 2006; Du Toit & Roodt, 2009; Kraak, 2005; Scott, Yeld & Henry, 2007) with the first year Mathematics pass rates in engineering equally disastrous (Havola, 2010; Reyes, Anderson-Rowland & McCartney, 1998). Globally lecturers complain that first year students lack the mathematical competencies that they should have acquired at school and that are required in higher education (Engelbrecht, Harding & Phiri, 2009; Fisher, 2011; Jansen, 2007). Fisher (2011) asserts that despite achieving in the top 10% of their cohort many students who enter engineering are academically underprepared. On the basis of this ECSA commissioned a study that would make recommendations to enhance the throughput in engineering. The National Development Plan indicates that "to promote lifelong learning, post-school institutions should accept students who are academically less prepared and provide them with targeted support" (National Development Plan, 2011, p. 316). Higher education institutions are urged to provide the academic support that students need. While students are accepted into engineering on merit on the basis of their Mathematics, English and Science performance, the statement made by the National Development Plan (Department of Education, 2011) carries with it deficit notions of the student. Ways in which the notions of deficit, widened access and low pass rates in mathematics are articulated in the teaching and learning environment are fore grounded in this study which seeks to understand how teaching and learning is approached in the ME module in engineering.

Engineering is a constantly evolving profession, in the last few decades growing exponentially with developments in both technology and society. The ME module provided by the mathematics department as a service module to engineering is a compulsory module for all engineering degrees. Hence, as providers of a core service module within engineering, the need for the mathematics department to work in congruence with the School of Engineering is requisite. Given the diverse composition of the student body, advances in technology and evolution in engineering practice, higher education is presented as a landscape that is fraught with challenges and changes that foreground the need to look into approaches to teaching and learning in higher education. The purpose of this study is to explore teaching and learning in an ME module in the engineering curriculum at a higher education institution. The mathematics department, has the responsibility of providing future engineers with the mathematical understanding required to participate effectively in further engineering modules and as professional engineers. It is important to understand how the mathematics taught in the ME module fits into the whole engineering programme at the university, and into the statutory requirements of the professional engineering body, ECSA. This insight will allow for a better and more nuanced understanding of the demands and requirements of the module.

In this study lectures, tutorials and assessments are identified as key focus areas. Understanding how teaching and learning Mathematics is approached in the engineering curriculum at SAHEI requires an understanding of mathematics in the engineering context and this motivated the first research question:

> Research Question 1: What is the role of mathematics in the education of future engineers?

For me, exposure to the context of engineering has brought with it many different challenges, with issues of retention and graduation being the prime concern. In my previous post as an academic development officer (ADO) I was required to liaise with academics and students in an effort to enhance student performance and this takes place in a context in which institutional efforts to improve throughput seem to be directed toward ‘fixing’ the student. While I acknowledge that working in this environment has broadened my understanding of the context of engineering, it has also raised many questions about teaching mathematics to future engineers. I am neither an engineer nor a student and as such, my involvement is to some extent from the periphery. This positions me appropriately to conduct this research.

One of the biggest challenges to mathematics educators in engineering education today is finding ways to meet the challenge of teaching an increasing and diverse student body (Croft & Ward, 2001) whilst simultaneously trying to accomplish the goals of the mathematics department. In addition, teaching and learning needs to be aligned to achieve the outcomes of the professional accreditation body, the school and the institution. This is compounded by the demands made on academics to increase their research productivity and improve the retention and graduation rates in engineering. A recent report reveals that:

> Measures such as graduation rate calculations or cohort studies are useful indicators of the need to investigate more deeply and systematically the process of teaching and learning and how … lecturer's pedagogical resources and the institutional environment combine to produce different academic results. (CHE, 2010, p. 6)

The mission of the SAHEI is well articulated in its statement which envisages the institution as a truly South African institution that prides itself on academic excellence, innovative research, demographically representative whilst redressing disadvantages, and inequities of the past (SAHEI, 2012b). Key to the achievement of this institutional mission is the principles and values which form the framework for its achievement. These include the institutions pledge to respect the right of students to participate in critical inquiry, and engage in intellectual discourse and to appreciate the diversity of students provide a student-centred environment, with curricula that are designed around their needs (SAHEI, 2012b). The mission statement and the ensuing principles and values highlight the need to provide an education that gives students from diverse educational and socio-economic backgrounds equal opportunities and access to success in the SAHEI. I acknowledge that while access to higher education has widened for students, I am concerned about whether the doors to higher education have been opened sufficiently wide for students to gain epistemological access to knowledge. These concerns motivate the second key research question:

> Research Question 2: How is teaching and learning in the ME module approached in lectures, tutorials and assessments?

In a systematic review of the literature on research in mathematics education, it emerged that, in the context of teaching mathematics to future engineers, countries across the world are experiencing difficulties similar to those mentioned above: Large student numbers due to widened access to higher education; diverse student bodies in terms of mathematical competencies and language and learning styles (Broadbridge & Henderson, 2008; Holton, 2001). These researchers draw on the socio-economic context in order to argue that failures in learning are due to the inferior educational experiences of the majority of students which have resulted in their failure to develop their cognitive capacities to the full and the lifelong learning skills necessary to succeed in higher education (Boughey, 2009). According to Boughey (2009) these justifications indicate that the dominant perception of the student experience seems to be informed by the model of 'student deficit' with a focus on academic support rather than academic development (Boughey, 2009):

> In spite of this tendency to draw on context to explain poor learning and what, in liberal terms, is construed as disadvantage or under preparedness, what remains is essentially an autonomous model which locates the capacity (including will) to learn within individuals. (p. 2).

This implies that the reason for student under performance is located within the student thereby absolving teachers and the quality of teaching from responsibility. When I encountered these explanations and perceptions, they raised another question. Have these beliefs about student performance impacted on teaching and learning mathematics to future engineers? Approaches to teaching and learning mathematics often reflect academics' underlying beliefs about the nature of mathematics and how it should be taught. This motivated the third research question which explores why teaching and learning mathematics is undertaken by academics in the particular ways that they choose:

> Research Question 3: Why is teaching and learning in the ME module approached the way it is, in particular what beliefs do academics have about teaching and learning mathematics to engineering students?

The issues of access, participation and equity, tied inevitably to retention and throughput rates dominate discussion in the SAHEI and the school of engineering and are a particular focus of my work. Fisher (2011) proposed that one of the factors influencing retention and throughput is student performance in the first year mathematics module. His research indicates that from 2006 to 2009, the failure rates for first year mathematics in engineering were significantly high. Widened access to engineering, the challenges of an evolving engineering landscape and the changing student profile marked by varying mathematical competences, socio-economic standing and issues of cultural capital which together constitute a formidable context for teaching and learning mean that the study of teaching and learning in the first mathematics module for engineering students is thus of prime importance.

The previous section has outlined the motivation for the focus of the research and how the research questions were derived. They are repeated here for clarity: (a) Research Question 1: What is the role of mathematics in the education of future engineers?; (b) Research Question 2: How is teaching and learning in the ME module approached in lectures, tutorials and assessments; and (c) Research Question 3: Why is teaching and learning in the ME module approached the way it is, in particular what beliefs do academics have about teaching and learning mathematics to engineering students? The next section presents the context of the study.

1.3 Specific Context of the Study

Post-apartheid education in South Africa sought to close the gap between school knowledge and everyday knowledge (Taylor, 2000). The approach adopted in South Africa was an Outcomes-Based Education (OBE) which,

> involves the most radical form of an integrated curriculum … Not only are we integrating across disciplines into Learning Areas, but we are integrating across all 8 Learning Areas in all educational activities … The outcome of this form of integration will be a profound transferability of knowledge in real life. (South Africa DoE, 1997, p. 29)

In 2012, students registering for the first time in engineering had been educated in and completed their school leaving examination under this system of OBE.

Young (2009) in his article, *What are Schools for?*, indicates that the role of schools is two-fold. Firstly, it is an attempt to address the economic needs of the country by promoting massification of schooling. Secondly, it is for schools to market themselves, to recruit students and attract funding. Extending this concept to higher education and to the SAHEI in particular, the institution considers itself a research led university and articulates one of its goals as enhancing its status in research by establishing a research culture that nurtures postgraduate students, and excelling as producers of new knowledge on national and international levels to achieve the institutional vision. Charged with the task of furthering these aims, the SAHEI has increased the number of students significantly, especially in disciplines such as engineering. To compete on a global level the SAHEI, like other HEIs, needs to attract funding and establish itself as a research-led institution. Higher throughput rates, greater numbers of postgraduate students and increased research productivity are necessary to catapult the HEI into world class rankings and attract funds to the institution. This is sufficient motivation to prioritise research and postgraduate study at the SAHEI.

The SAHEI is the culmination of the merger and restructuring of two universities. Of relevance to this study is that the School of Mathematics and the School of Engineering sit on different campuses which are within ten kilometers of each other.

Between 2007 and 2011, the entire cohort of students was divided into two groups to accommodate the large number of students and the ME lectures were delivered by team teaching. Specific lecturers were responsible for certain topics in the syllabus. It was hoped that the team teaching would ensure consistency and standardisation of the topics covered by the two groups with respect to content and teaching style. The benefits of this were twofold: no single student was either advantaged or disadvantaged with regard to lecture style and syllabus coverage and it reduced the number of topics that each lecturer had to teach thus allowing them to focus on topics that they were strong in and to plan and prepare accordingly.

In 2012, the year in which this study was conducted, students registered for the mathematics modules were divided according to the engineering disciplines that they were enrolled for. The mechanical and chemical engineering students formed a group, the agricultural, electronic and electrical engineering students another while the third group comprised civil and computer engineering students and included land surveying students.

1.4 Significance of the study

It is hoped that this research has the potential to help us understand the teaching and learning of mathematics amongst engineering students, identify limitations, challenges and areas of improvement to suggest strategies that can be used to enhance teaching and learning. In the past, research has often led to the development of teaching and learning strategies which have been effective (Artigue, Hillei, Holton & Schoenfeld, 2001) in enriching the current knowledge base in this area of research. There is little research in recent years that address issues of teaching and learning mathematics to future engineers at the SAHEI. The findings from this study can be used to enrich the knowledge base in this area of research and addresses the silence in the literature. It is hoped that this study will highlight the dialectic relationship between teachers of mathematics and engineering academics and provide the opportunity to improve the teaching and learning of mathematics to future engineers.

1.5 Paradigmatic Location of the Research

This study was a case study of the ME module for first year engineering students and was conducted in the first semester of 2012. This case is an instance of a core module in the engineering degree programme for first year engineering students. The paradigmatic orientation of this study is pragmatism, evidenced in the use of a mixed methods approach. Methods that provided opportunities that best supported the collection of data to answer the research questions were adopted. Data were collected from lectures and tutorials and academics, tutors and students involved in the module.

1.6 Overview of the Thesis

This chapter has described the motivation and context of the study, the key research questions and a brief overview of the paradigm within which this study was conducted. Chapter Two presents the theoretical and conceptual frameworks. It presents Bernstein’s theory of the pedagogic device which is used to analyse the structure of the module in terms of the three message systems. The construct of beliefs is discussed here and is used to analyse the teaching styles of lecturers. Finally Bloom's revised taxonomy is explained as it provides the analytical framework to determine the quality of the final examination questions in terms of cognitive demand. Chapter Three presents a discussion of theories of teaching and learning in the field of mathematics and engineering education adopted by institutions across the world. The discussion considers justifications for the choice of teaching and learning approaches in these institutions. An overview of theory and research that pertain to the development of methods for teaching mathematics to engineers is presented. A discussion of teacher beliefs and their influence on teaching and learning is presented, with particular emphasis on teaching approaches, assessment strategies and tutorials. Chapter Four is a description of the research design and methodology. A justification for the paradigmatic orientation of the study is provided, while the methodological approach and the use of a case study are justified and described. The data collection methods and data analysis together with issues of reliability, validity and ethics are discussed. Chapter Five presents the findings of research question one which seeks to determine the role and relevance of mathematics in engineering at the SAHEI. This chapter discusses the reasons underlying the international concern and significance attributed to the role of mathematics in engineering. The requirements of the international and national statutory bodies and the institutional requirements are presented. Finally, a detailed description of the ME module is presented to show how the institution has taken the requirements forward. Chapter Six presents the findings of research question two: How is teaching and learning ME approached? A description of the mathematics department, the student profile and the organisation of the ME module as well as the findings from the analysis of the three message systems using Bernstein's concepts of recontextualisation, singulars and regions and classification and framing are presented. Chapter Seven presents the findings of the third and final research question which asks why teaching and learning in the ME module is approached the way it is, in particular what beliefs do academics have about teaching and learning mathematics to engineering students? A summary of the findings which emerged from observations and interviews with lecturers and students are presented as three case studies nested within the larger case study of the ME module. Chapter Eight presents a summary of the findings brought about by the three research questions and a discussion of their implications for teaching and learning. In conclusion, Chapter Nine presents recommendations for teaching and learning mathematics to future engineers and suggestions for further research.

Chapter Two
Theoretical and Conceptual Frameworks

Chapter One provided the motivation for this study, introduced the changing higher education landscape in South Africa and gave an overview of the thesis. The focus of this chapter is to present a detailed discussion of the theoretical framing underpinning the study. The chapter begins with an exposition of Bernstein's theory of the pedagogic device which explicates recontextualisation, singulars and regions and classification and framing. Since the ME module is designed and delivered by the mathematics department but forms part of the engineering curriculum, a discussion of disciplines as regions and singulars, as expounded by Bernstein is given. This is followed by a discussion of Bernstein's concept of classification and framing. Classification is used to analyse the extent of integration between mathematical content and other content while and framing examines the extent of control that teachers and students have over selection, sequencing and pacing of content and evaluative criteria. Following this is an exposition of vertical and horizontal discourses, abstract and theoretical knowledge and the development of Bernstein's theories. The basis of Bernstein's theories and models is an attempt to explain social class differences in relation to the curriculum and so a discussion about access to abstract knowledge is included. Following this is a discussion of teachers' philosophical and epistemological conceptions about the nature of mathematics and mathematics teaching. Bloom's revised taxonomy is presented next because it was used to determine the quality of assessments in the module. This chapter concludes with a summary of the salient points discussed.

The theoretical framing of this study is strongly underpinned by Bernstein's theories. The term teaching and learning approach, as used in this study, correlates strongly with the term 'pedagogy' as referred to by Bernstein (2000) and so it is appropriate to clarify the meaning that he attributes to the term 'pedagogy'. The definition of 'pedagogy' used by Bernstein:

> Pedagogy is a sustained process whereby somebody (s) acquires a new form or develops existing forms of conduct, knowledge, practice and criteria from somebody(s) or

> something deemed to be an appropriate provider and evaluator –appropriate either from the point of view of the acquirer or by some other body(s) or both. (2000, p. 78)

2.1 The Pedagogic Device

Bernstein explains that "between power and knowledge and knowledge and consciousness is always the pedagogic device" (Bernstein, 1990, p. 181). The development of Bernstein's theory, to focus on the transformation of disciplinary knowledge into pedagogic communication, provides a social lens through which the higher education context can be interrogated. This section of the chapter focuses on the use of Bernstein's pedagogic device as the theoretical framework that will be used to analyse and interpret how disciplinary knowledge is transformed into pedagogic communication in the ME module at the SAHEI.

According to Bernstein, "curriculum defines what counts as valid knowledge, pedagogy defines what counts as valid transmission of knowledge, and evaluation defines what counts as a valid realization of the knowledge on the part of the taught" (1973, p. 85). His concepts of classification, framing, and evaluation form the basis for understanding his theory of curriculum. This calls into question the development and structure of the different forms of knowledge, which according to Bernstein are a result of the pedagogic device. The pedagogic device is a set of principles that describes the transformation of knowledge from the field of production into the educational context and its distribution and evaluation (Bernstein, 1996). Many authors have subsequently written widely in the field (Bennet, 2002; Ferreira, Morais & Neves, 2011; Geirsdottir, 2008; Hoadley, 2006; Jober, 2012; Mclean, Abbas & Ashwin, 2011; Morais & Neves, 2012; Young & Muller, 2010). The pedagogic device is described as the principles that regulate the structuring and distribution of knowledge in the educational system (Mclean, Abbas & Ashwin, 2011) and as a collection of rules that form the basis for analyzing the transformation of knowledge into educational content and pedagogic communication (Singh, 2002). In the pedagogic device, Bernstein seeks to explore the construction of the sociological nature of pedagogic knowledge (official or local) which allows for the interrogation of the ways in which "the substance and nature of the message" is relayed (Bertram, 2008), making the focus the structure and organization of the content and the distribution of that relay (Bernstein, 1996, 2000; Bertram, 2008). In terms of the ME module, the recontextualisation and regionalization of mathematical knowledge from its source in the academic discipline of mathematics to the ME module and the influences that act to shape the module in the way that it is, are investigated. Furthermore the content, pedagogy and assessment are examined to elicit *what* is transmitted and *how* that transmission occurs with regard to selection, sequencing, pacing and evaluative criteria.

The pedagogic device consists of internal rules that regulate pedagogic communication which in turn act selectively to regulate pedagogic meaning of the discourse making it accessible to those who have access to internal rules. The quality of the resulting pedagogic meaning determines the quality and quantity of learning that takes place (Bernstein, 2000). Bernstein refers to learning as realizations and explains that various realizations are possible because the rules vary according to the context and are ideologically-laden, privileging dominant social groups. He explains that social groups fight for control of the device because it is through this ownership that they maintain their own powerbase. The owners of the device can then attempt to exert their own ideological influence on the generation and transmission of knowledge and so entrench hegemony (Bernstein, 1996).

The construction of the internal structure of pedagogic discourse and the principles underpinning this construction are explicated in three interrelated and hierarchically organized rules which constitute the pedagogic device. The three rules are the distributive, recontextualising, and evaluative rules. The hierarchical relationship is explained by the relationship between these rules since distributive rules influence recontextualising rules which in turn influence evaluative rules (Bernstein, 1996). The pedagogic device shows how the distributive, recontextualising and evaluative rules interrelate to relay society's power relations and pedagogic practices which mediate access to knowledge ultimately serving to include or exclude. This means different social groups gain access to different forms of knowledge and therefore differentiated "access to the 'unthinkable', that is to the possibility of new knowledge, and access to the 'thinkable' or official knowledge" (Bernstein, 1996, p. 117). The three rules operate within different fields, namely the field of production, field of recontextualisation and field of reproduction.

Distributive rules operate within the field of production, recontextualising rules within the field of recontextualisation and evaluative rules within the field of reproduction. Underlying these three fields is pedagogic discourse which is constituted through classification and framing as well as recognition and realisation rules (Bertram, 2008). Table 2.1 tabulates the rules of the pedagogic device, the fields in which they operate and the agents which reside in each field. The pedagogic device is viewed as a key element of cultural reproduction because it establishes the relationship between power, knowledge and consciousness. It distributes the power ingrained in educational knowledge through the distributive rules.

Table 2.1

Rules of the Pedagogic Device (Adapted from Bertram, 2008)

Category	Distributive	Recontextualising	Evaluative
Fields	Production	Recontextualisation	Reproduction
Agents	Producers of knowledge, Higher education institutions	National departments of education, Head of subject, Textbooks and textbook authors, Professional bodies, International alliances,	Lecturers or teachers in the education system including HEIs and the schooling system
Resources	Generally the HEIs	National plan for Higher Education, Professional body policies, Textbooks, Head of School, Lecturers	Lectures, Tutorials, Assessments

Subjects (students) internalise this power and acquire specific consciousness via the evaluation rules according to their different positions in society. Each of these components is discussed below.

2.1.1 Distributive rules. Bernstein, (2000) used distributive rules to distinguish between two kinds of knowledge, which he calls ‘thinkable’ or mundane knowledge and ‘unthinkable’ or esoteric knowledge. For simplicity I will refer to the two forms as ‘thinkable’ and ‘unthinkable’ knowledge. He explains that the interplay between the two is dynamic. It has the potential to change based on whom has control over the educational (or other) system (Bernstein, 1996). Esoteric knowledge tends to be generated and used in higher levels of the education system, such as institutions of higher education, while mundane knowledge is mostly found in the schooling system (primary and high schools). Bernstein argued that between the esoteric and mundane worlds is a relationship which creates a specific order of meaning. The order of meanings created between the material and immaterial worlds has an indirect relation between itself and the material base thus creating a gap, which Bernstein refers to as the ‘potential discursive gap’. This gap has the potential to become a site for alternative possibilities which can be simultaneously both beneficial and dangerous and is thus the site of the ‘yet to be thought’. Thus the relation between the material and immaterial has the potential to create alternative realizations which have the potential to change due to the discursive gap (Bernstein, 1996, 2000).

Distributive rules regulate this potential discursive gap by regulating “the relationship between power, social groups, forms of consciousness and practice” (Bernstein, 2000, p. 28) thus specializing forms of knowledge, consciousness and practice to social groups. Distributive rules regulate who transmits “what to whom and under what conditions” as they attempt to set the outer limits to legitimate pedagogical discourse (Bernstein, 2000, p. 31) including ways of thinking, speaking, behaving and ordering that are privileged by the distributive rule (Ensor, 2004). Thus distributive rules regulate “what can legitimately be taught in university, who may legitimately take on the role of the teacher or learner and the conditions under which teaching-learning processes take place” (Ashwin, 2009, p. 91). These rules operate through the specialisations of different agencies to regulate the relation between the ‘thinkable/unthinkable and respective practices’ and are therefore responsible for the relations between categories. Contexts and content become the means through which specialised pedagogic subjects are selected and created by the pedagogic discourse (Bernstein, 2000).

2.1.2 Recontextualising rules: Pedagogic discourse. It is through the principles of pedagogic discourse that forms of knowledge become part of the teaching and learning practice and over time change in institutional pedagogy becomes an ongoing process. Recontextualisation is the process of selectively transforming knowledge from the site of production (in this case the higher education institutions) to the site of reproduction, that is the ME module in the SAHEI (Bertram, 2008). This means that pedagogic discourse regulates the discourses to be transmitted (the *what*) as well as the principles of transmission and acquisition (the *how*) (Bernstein, 2000). Recontextualising rules comprise specific pedagogic discourses (Bernstein, 2000, p. 31) which underlie the fields of production, recontextualisation and reproduction.

Bernstein describes the pedagogic discourse as a principle which embeds two discourses: the *instructional discourse* (discursive rules) and the *regulative discourse* (discourse of *s*ocial order). The first discourse involves encompassing skills of various types and the relations between them and is referred to as instructional discourse or *discursive rules*. Discursive rules are "concerned with the transmission/ acquisition of specific competences" (Bernstein, 1990, p. 211), that are a reflection of the control exerted by transmitters and acquirers. The instructional discourse is embedded within the regulative discourse making the relation between the two, hierarchical. Second is the discourse of social order which is referred to as *regulative discourse* (Bernstein, 1990, 2000). Regulative discourse "is concerned with the transmission of principles of order, relation and identity" (Bernstein, 1990, p. 211). Regulative discourse regulates the selection, sequencing, pacing and evaluative criteria of the instructional discourse (Hoadley, 2006). The regulative discourse is the dominant discourse as it provides the moral dimension which creates the rules of social order. The rules of social order are concerned with theories underpinning pedagogy as well as the legitimate expectations in terms of character, conduct and manner, otherwise known as the 'hidden curriculum' (Hoadley, 2006). The regulative discourse is thus concerned with translating the dominant values of society and regulates the order of the instructional discourse (Bernstein, 2000) thus regulating the form of *how* knowledge is transmitted (Morais, 1996). Recontextualising principles move the discourse so that it becomes both subject and content of the pedagogic practice. This also involves recontextualising the theory of instruction which constitutes a model of the learner, the teacher, and the relation between them. The recontextualising principle thus selects the *what* and the *how* of the theory of instruction, both of which are elements of the regulative discourse.

Bernstein notes that some theorists consider the transmission of content and the transmission of values as independent processes. However he considers them a single discourse claiming that both work together to produce a single voice and a single legitimate text (Bernstein, 2000). Muller (2007) whilst discussing Bernstein's paper titled *Vertical and Horizontal Discourse*, points to the author's view that instructional discourse has an internal logic of its own. This calls into question the complete dominance of the regulative discourse over instructional discourse. The question raised is whether knowledge structure influences the recontextualisation of content. Bertram argues that if recontextualisation cuts off the content from the discipline how is specialised knowledge ever reproduced? In support of her argument, she suggests that there must, therefore, be some relationship between school knowledge, university knowledge and the field of production (Bertram, 2008).

Pedagogic discourse is described as a principle which selectively appropriates other discourses and brings them into a special relationship with each other with the intention of selective transmission and acquisition (Bernstein, 2000). In this process pedagogic discourse selectively delocates a discourse, for the purpose of relocating it and refocusing it according to its own principle or order (Bernstein, 2000). This delocation of the discourse creates a gap in which ideology can exert an influence thus creating a discourse which has been ideologically transformed. To exemplify this I will use mathematics as a discourse in the field of production and Mathematics for Engineers as a pedagogic discourse. The activities of the mathematician pertain to the production of knowledge in the field of mathematics and are different from the activities of the authors of mathematics textbooks, who might not be practicing mathematicians, involved in the field of production of mathematics. These authors of textbooks work in the field of recontextualisation and select from the field of production of mathematicians, what is to be included in the pedagogy of mathematics for engineers. As rules are based on social fact, this involves the principles of selection in the relation between mathematics and other subjects (Bernstein, 2000). It is in the selection process that the dominant ideology influences the *what* of the content.

The recontextualising rules operate within a field that consists of agents and their ideologies and can be distinguished into official recontextualising fields (ORF) and the pedagogic recontextualising fields (PRF). The ORF is regulated by the State and related agents and operates at the generative level to legitimate the distribution of power and principles of control. The PRF consists of agents who reside, for example, in the education system or department of education. An absence of the PRF suggests there is no autonomy over the pedagogic discourse and practices while the presence of a PRF affects the pedagogic discourse by providing some autonomy. However, with autonomy comes conflict over the pedagogic discourse and its practices (Bernstein, 2000). The pedagogic discourse produced can undergo further recontextualisation at the level of transmission when confronted with the specific contexts and pedagogic practices of academics in the classroom. This illustrates the dynamism of the pedagogic discourse which is influenced by relationships typifying the transmission context thereby acting as a catalyst for change. Change is more likely to occur in instances where the pedagogic device is able to provide more recontextualising possibilities. Figure 2.1 illustrates Bernstein's model of the pedagogic discourse.

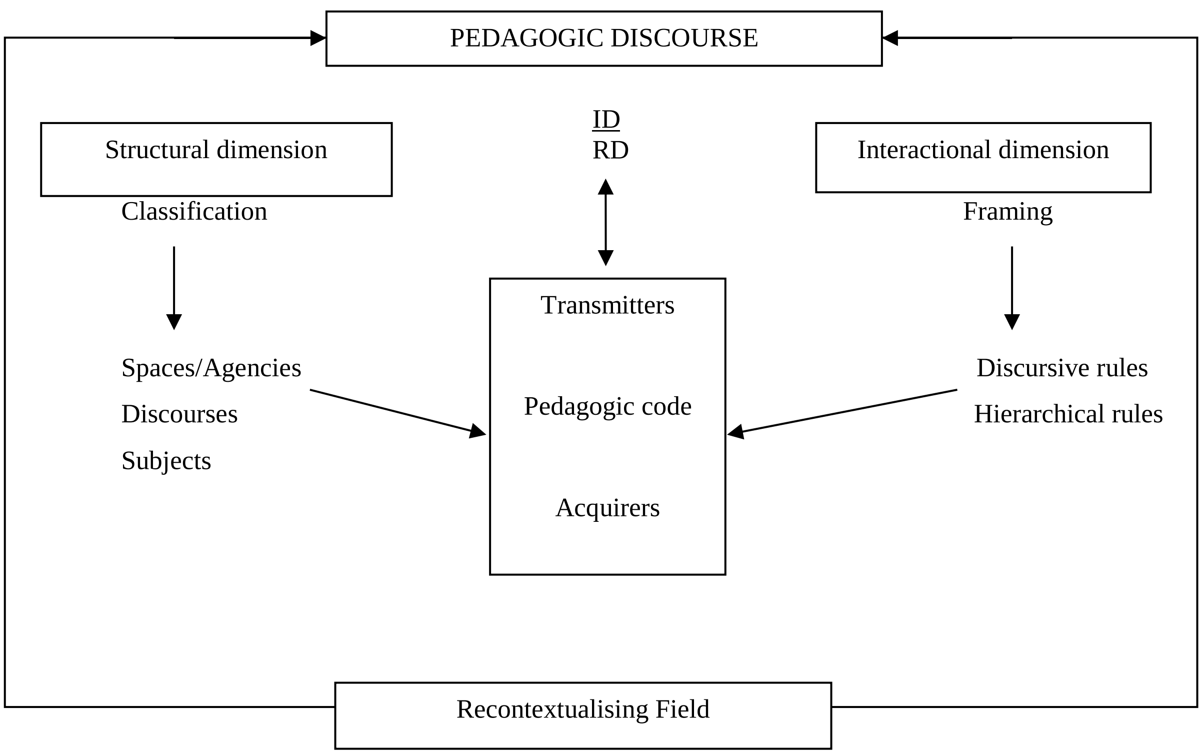

Figure 2.1 Bernstein's model of pedagogic discourse (Adapted from Morais &Neves, 1986)

Recontextualising rules regulate evaluation rules which govern the relations between transmission and acquisition in specific pedagogic discourses. Evaluative rules construct pedagogic practice and the criteria to be transmitted and acquired.

2.1.3 Evaluative rules. Evaluative rules are significant as according to Bernstein, "Evaluation condenses the meaning of the whole device which is to provide a symbolic ruler for consciousness" (Bernstein, 2000, p. 32). Pedagogic discourse at the most abstract level specializes time, space and text into a special relationship with each other thereby attaching meanings to time and space (Bernstein, 2000). Bernstein claims that any pedagogic discourse punctuates time to create age stages that are entirely imaginary and random. Text is transformed into a specific content, and space into a specific context. Age, context and content are eventually transformed into pedagogic practice and communication, where age is transformed into acquisition, content into evaluation and context into transmission. Bernstein states that the key to pedagogic practice is constant evaluation. Evaluation condenses the meaning of the pedagogic device (Figure 2.2).

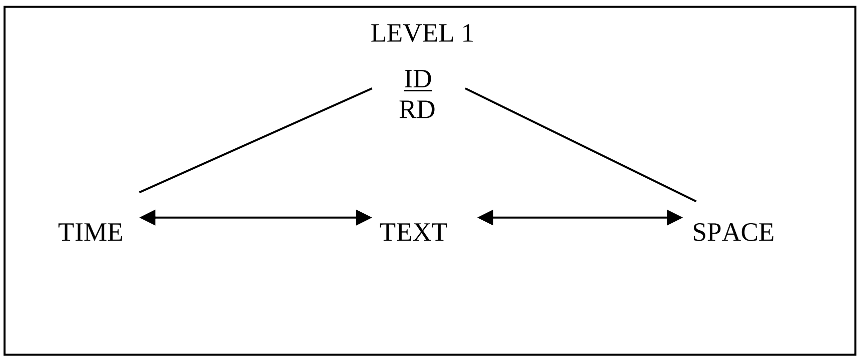

Figure 2.2 Relationship between time, text and space (Bernstein, 2000, p. 35)

Consequently the pedagogic device is the symbolic ruler for consciousness (Bernstein, 2000). While recontextualisation explains the transformation of knowledge from the site of production to the site of reproduction, singulars and regions also influenced by recontextualising principles address the different ways in which knowledge is organized. Discourses as singulars and regions are discussed next.

2.2 Discourses as Singulars and Regions

The increasing complexity in the social division of labour paved the way for the emergence of specialized bodies of knowledge which required knowledge to be organized in different ways. Singulars and regions are two distinct ways in which knowledge can be organized (Bernstein, 2000). Singular discourses refer to discourses where the discourse pertains to specialized knowledge structures with few external references which focus on the production of knowledge within that discourse. Essentially singulars are discourses which have very few external references and are predominantly about themselves (narcissistic). Subjects such as Mathematics, Physics and Chemistry are examples of singulars. In recent years, what has emerged is the 'regionalisation of knowledge' which results in a "region [that] is created by a recontextualising of singulars" (Bernstein, 2000, p. 9). That is, academic disciplines are the underpinning theoretical basis for the development of regions which face inward towards academic disciplines and outward toward the field of practice. Medicine, engineering and architecture are examples of regions which indicate how the regionalization of knowledge has developed. According to Bernstein (2000):

> Regions are constructed by recontextualising singulars into larger units which operate both in the intellectual field of disciplines and in the field of external practice. Regions are the interface between disciplines (singulars) and the technologies they make possible (p. 52).

Regions, for example engineering, are found at the interface between singulars (generally an academic discipline) and the field of professional practice (Wheelahan, 2012). The regionalisation of knowledge implies a recontextualising principle that has to determine in which singulars knowledge is to be regionalized, what knowledge from the singular is to be regionalised and how it is to be related. Hence regions are constituted from the knowledge of many singulars whereas singulars are concerned with the production of knowledge in its own intellectual field. Furthermore, "regions are the interface between the field of the production of knowledge and any field of practice and, therefore, the regionalization of knowledge has many implications" (p. 9). For example, the regionalization of knowledge results in changes in the classification of knowledge as boundaries weaken creating the space for the development of new power relations between regions and singulars. Bernstein asserts that it is necessary to have an understanding of the recontextualising rules that construct the new discourse as well as its underpinning ideological bias. The construction of a new discourse creates a space in which ideology comes into play, as new power relations are created between singulars and regions initiating a power struggle for resources and influences (Bernstein, 2000). Within the context of this study, theoretical mathematics is classified as a singular, being a discipline which looks ‘inward’ and as such is concerned with production of knowledge within the discipline itself. Regions face “inwards towards the field of production and outwards towards external fields of practice” (Bernstein, 2000, p. 52). Engineering is considered a region, as it lies at the interface between the site of the production of knowledge (higher education) facing ‘inward’ towards academic disciplinary knowledge and ‘outwards’ towards the external field of practice as it is considered a professional degree (Bernstein, 2000).

Bernstein contends that the social division of labour is an expression of power which manifests in the classification of knowledge and which are differentiated on the basis of their specialization. The degree of specialization is indicated by the extent to which they are insulated or differentiated from other categories of knowledge. The relations of power and control are evident in the different ways in which knowledge is classified and framed as singulars or regions. Academic disciplines are singulars as they are strongly classified in terms of the knowledge base and are interested in their own self-importance, “orientated to their own development, protected by strong boundaries and hierarchies” (Bernstein, 2000, p. 152). This highlights the tension that is inherent in the ME module by virtue of its position as a subject within the field of mathematics as a singular discourse, but which is a core module within the field of engineering as a regional discourse. Bernstein claims that the formation of pedagogic codes occurs within the recontextualising field and reproduces and recontextualises knowledge for the curriculum.

Within the micro level, for example in a university, very strong classification between inside and outside spaces specialises the knowledge creating a hierarchy of knowledge between common sense and uncommon sense. In this scenario, Bernstein (2000) suggests that academic staff is attached to their departments. He suggests two reasons for this. First he says that perhaps the sacred reason for the attachment is internal cohesion by virtue of their category and second for promotion purposes, which he says are awarded on the basis of engaging in appropriate activities. This implies that commitment to the organizational base and the category takes precedence over their intrinsic function of reproducing pedagogic discourse. This type of relation between staff weakens communication between them concerning pedagogic discourse since each are differently specialized. On the other end of the spectrum, institutions exhibiting weak classification, render the institution vulnerable to communication from the outside and prevent an institutional identity from being established by the organizational structure. The staff is part of a strong social network and relations between them revolve around knowledge. This constructs a new power base making the power lines more complex and resulting in a reordering of specialised differentiation. This, in turn leads to a new social basis for consensus of interest and opposition (Bernstein, 2000).

Within the higher education system, the social division of labour is constituted by categories labeled as modules and disciplines and may be exemplified by the relation between them. Within the field of engineering, which may be regarded as a region, students enroll in four core modules in the first semester of the first term. One of these modules is the Mathematics for Engineers (ME) module which is offered as a service module by the discipline of Mathematics, to engineering students. Hence at the very outset there is a distinction on the basis of discipline. At the next level, ME is similar to the three other modules offered as service modules, Chemistry for Engineers, Physics for Engineers and Applied mathematics for Engineers and yet different in that ME is also a fundamental component in each of the other modules. Strong classification in this module would indicate a high degree of insulation between the content of different modules and disciplines. In addition it would show that each of the categories has their unique voice which ensures that transmitters and acquirers establish specialized categories with unique voices. Weak classification would be indicative of a high level of integration of content between topics in the ME module, disciplines and modules.

2.3 Classification and Framing

Through the social division of labour evident in the existence of different social positions, the different specializations of society produce different codes of language that serve to either privilege or disadvantage them educationally (Maton & Muller, 2007). These codes are valued differently in the education system with the different social positions explained by Bernstein as creating "different modalities of communication differentially valued by the school, and differentially effective in it, because of the school's values, modes of practice and relations with its different communities" (Bernstein, 1996, p. 91). Code is understood to refer to "a regulatory principle governing the selection and permitted permutation of curricula and linguistic elements" (Atkinson, 1985, p. 90). The function of the regulatory principle is to bring about different forms of surface realizations thereby invoking the concept of boundary. The concept of boundary operates on the concept of classification.

2.3 1 Classification. Bernstein (2000) defined the concepts of classification and framing which provide the means to understand how the process of symbolic control is regulated by different modalities of pedagogic practice. On a macro level, classification analyses the relations between agents and discourses that make up the categories. On a micro level, the analysis focuses on how pedagogic practice is organized and structured (Hoadley, 2006). Dominant power relations establish relationships between categories. Agents may be teachers or students or both while discourses may refer to for example, mathematics, chemistry and physics. The discourses of mathematics, physics and chemistry may be taken to be the social division of labour of discourse which if they are differently specialised, must have a space to develop their own specialized identity with its own internal rules and specialized voice. The strength of the space between categories defines its own uniqueness, own rules and distinct voice. Each category has its own unique identity that can only be maintained and reproduced through the insulation of it from other categories. Bernstein writes:

> A can only be A if it can effectively insulate itself from B … if that insulation is broken, then the category is in danger of losing its identity, because what it is, is the space

> between it and another category. Whatever maintains the strength of the insulation, maintains the relations between the categories and their distinct voices. (2000, p. 6)

Boundaries are grounded in two fundamental principles: "where we have strong classification, the rule is: things must be kept apart. Where we have weak classification, the rule is: things must be brought together" (Bernstein, 2000, p. 11). The principle, *things must be kept apart* is a reflection of a strong boundary between categories (C+) while the principle *things must be brought together* is a reflection of a weak boundary between categories (C-). Strong classification indicates a distinct separation or insulation between categories reflecting a hierarchy that is strong, with a dominant voice and power and the opportunity for the development of 'specialised' identities (Hoadley, 2006; Mclean *et al*., 2011). Weak classification results in weak insulation between categories. This results in a weak specialization of categories and reflects a weak hierarchy. In this scenario, the category is in danger of losing its identity.

The concept of classification asks questions about in whose interest it is to keep things apart or to keep things together (Bernstein, 2000). This is explained using two examples provided by Bernstein. The first is that of a society characterized by a distribution of power that is equitable and by principles of control that are based on a horizontal social structure. In this scenario society displays a dominant code which legitimates weak classification and framing. The second is a society characterized by distribution of power and principles of control that are based on a hierarchical social structure privileging a dominant code which legitimates strong classification and framing. Based on classification, Bernstein distinguishes between two types of curricula: the collection code and the integrated code.

The collection code typifies strong classification. This means that the knowledge of the discipline under scrutiny (thus entitling it to higher status) is prioritised over that of other disciplines motivating a collection curriculum. Traditionally a collection curriculum is differentiated into specialized subjects with knowledge regarded as sacred. Organisation of knowledge is hierarchical with little indication of how this fits into the rest of the academic curriculum. The teacher is seen as an authority in disciplinary knowledge, has a strong focus, loyalty and identity with the subject, teacher-student relationships are hierarchical and procedural. Students are socialized into regarding academic knowledge as different from everyday knowledge. A collection code demonstrates strong framing as it allows academics and students little control over the pedagogic relation in terms of what is to be transmitted and acquired. In addition, the process of teaching and learning encouraged is surface to deep structure of knowledge privileging deductive over inductive approaches (Harley, 2010) and demonstration of proficiency in the subject area is a prerequisite to promotion.

An integrated code indicates a weak classification and weak framing. Weak classification between disciplines is demonstrated when an interrelation between contents is present. This signifies an integration code which motivates the presence of an integration curriculum (Bernstein, 2000). Integrated code is reflective of weak classification where power is not held by the teacher but shared between teacher and student. This means that academics and students have greater ‘apparent’ control over the pedagogic relation. According to Harley (2010), an integrated code facilitates students’ access to deep knowledge structures. This code requires teachers to be knowledgeable of the discipline as they are expected to analyse and synthesise knowledge across topics or subjects. Supporting an integrated code environment requires a wider variety of assessment techniques as more student attributes need to be tested (Harley, 2010).

Bernstein uses the concept of classification to describe the translation of power and power relations that are realized in different modalities of pedagogic discourse and pedagogic practice (Bernstein, 2000). He states that:

> Power relations … create boundaries, legitimate boundaries, reproduce boundaries, between different categories… Thus power always operates to produce dislocations, to produce punctuations in social space. (p. 5)

Furthermore, he claims that what the boundary signifies is crucial in “condensing the past but not a relay for it, rather a tension between the past and possible future. The boundary is not etched as in copperplate nor as ephemeral as in quicksand and is sometimes more enabling than disabling” (Bernstein, 2000, xiii). By their very nature boundaries have the potential to change or maintain the status of power and control relations as they are dependent on the strength of boundaries. Muller (2000) claims that explicit boundaries provide students with access that will enable them to engage with, maintain or transform the boundaries.

Elaborated and restricted codes are two different orientations regulating access to meanings. In restricted codes, meanings are condensed with elaborated code, meanings are expanded. Mathematics is the purest of restricted codes due to its extremely "symbolically condensed expression of meaning" (Moore, 2013, p. 68) developed through several lower level theorems which can be applied consistently across disparate phenomena. Initiation into this code requires elaboration, condensing and progress to the next level of learning. This is exemplified by Moore who asserts that,

> Mathematics … are restricted codes of immense cognitive power based upon symbolically condensed orders of meaning. Access to these codes is through systematic disciplines of initiation based upon the initial elaboration of meanings at successive levels in which condensed meanings are *expanded* … for novices so that they, then, become *condensed* as taken for granted aspects of consciousness shared with others with similar levels of understanding (*a habitus*). (p. 69)

Assessments examine what the transmitter elaborates to acquirers through lectures, tutorials and the like (Moore, 2013). The key problem with access to meanings is the relationship between restricted and elaborated code as it is elaborated code that provides access to restricted codes. Using Fermat's theorem, Moore explains that "the meaning of a theorem is its proof" and while theorems are short, proofs which provide access to the meanings of it, are long and often only accessible to a few people. Proof is a sequence of theorems with lower order theorems subsumed in higher order theorems that can each be unpacked. The process of unpacking theorems is cyclical and involves elaboration of meaning which is condensed into restricted code (packed into higher order theorems).

The degree of classification can be calibrated as very strong (C++), strong (C+), weak (C-) and very weak (C--). A four-point scale is generally used to represent the extent of classification, although there have been modifications to the scale to include C0 which indicates that occurrences of a particular indicator may not have been available for measure at that point but not necessarily that it is permanently absent.

2.3.2 Framing. The concept of framing refers to principles of control which operate within categories (Bernstein, 2000). The concept of framing is a form of control "which regulates and legitimizes communication in pedagogic relations: the nature of the talk and the kinds of spaces envisaged" (Bernstein, 2000, p. 12). It provides the tools to "analyse the different forms of legitimate communication realized in any pedagogic practice" (Bernstein, 2000, p. 12). Framing establishes the degree of strength (F^+) or weakness (F^-) of the social relations or communication within categories (Atkinson, 1985). As framing is concerned with who controls what, it refers to the locus of control over the selection, sequencing, pacing and evaluative criteria of content and control over the social base which facilitates transmission. Strong framing (F+) signifies that categories with higher status exert a high degree of control over the social relations governing categories (Bernstein, 2000). Weak framing (F-) indicates that lower status categories have a say over social relations governing categories.

Hierarchical rules are crucial in characterizing pedagogic practice in the relationship between transmitter and acquirer. These rules govern the communication (relationship) characterized by the power differential (academic and student) (Bernstein, 1996). For example, in a teacher-student relation, strong framing privileges the teacher in terms of control of the organization of the knowledge, skills and discourses as the teacher is the authority and makes explicit the boundaries (Mclean *et al*., 2011). A weak framing privileges implicit boundaries where the locus of control is open and students have some degree of control. The socialization rules associated with weak framing encourage spontaneous behaviors which result in social relations and social types that are neither strong nor distinctive.

The relations reflected by classification and framing is a manifestation of the structure of socialization that has been established and the distinct rules. Be that as it may, Bernstein maintains that "control is double faced for it carries both the power of reproduction and the potential for its change" (1996, p. 19). Hoadley supports this when she says framing "allows for the … making and potential unmaking of the social reproduction of inequality" (Hoadley, 2006,

p. 7). Framing upholds classification since it produces the means to change the status quo. If the proposed change is initiated by the dominant group then it is likely that approaches privileging the status quo would be favoured whereas if the dominated group requested change then a dissident approach is likely to be privileged (Bernstein, 2000). In her paper titled *Knowledge Matters: interrogating the curriculum debate in engineering using the sociology of knowledge*, Case (2011) poses an interesting question: Whose interests does the curriculum serve and what kind of student does the traditional curriculum envisage? Historically the curriculum targeted small numbers of students, who stemmed from middle class families and were considered an elite group with good school backgrounds (Case, 2011). However, as established in Chapter One the current student profile is vastly different to that envisaged by a traditional curriculum. This creates the need to ask how responsive the current curriculum in the ME module is to the needs of the current student cohort at the SAHEI.

Framing is about who controls what and can be explained in terms of the internal logic of pedagogic practice, that is the extent of control over selection, sequencing, pacing and the evaluative criteria (Bernstein, 2000). Strong framing (F+) indicates explicit control by the transmitter while weak framing (F-) indicates implicit control by the transmitter or 'apparent' control by the acquirer. These activities are associated with control as it ultimately becomes the means by which students are socialized into particular identities. Framing could vary within the different elements of pedagogic practice. For example, the framing over pacing could be weak whereas other aspects of the discourse could be strongly framed (Bernstein, 2000). Acquirers are labeled according to the framing as follows: if the framing is strong, the acquirer is labeled as "conscientious, attentive, industrious, careful, receptive" (Bernstein, 2000, p. 13); if the framing is weak, the labeling is difficult as it will vary with the competences that the learner has acquired, making it difficult for the acquirer to acquire (Bernstein, 2000).

Hugo (2013) identifies downward or emergent selection as two ways in which selection of content occurs. Downward selection is evident in situations where people in authority have control over what is taught (strong framing). The normative dimensions of the society that encourages downward selection are those that privilege an ordered, pre-determined and structured society that fears corruption (Hugo, 2013). Emergent selection privileges selection from the bottom up with students having some control over the selection of content (weak framing). The society which favours an emergent selection is one that is typical of a free, self-organising society. This raises the questions: what affects how we view the selection of knowledge, what impacts on the selection mechanism and who has control over it (Hugo, 2013). The answer to this is dependent on who has greater access to information, the degree of specialization, the number of levels and layers required to develop the specialization, the dynamism of the forms of knowledge and the types of knowledge that exist. For example, science demonstrates fundamental demands that appear to be consistent globally. This attests to the view that mathematics and science are subjects that are considered hierarchical in nature and that "the higher levels demand that specific things are covered earlier on to enable their own possibility" placing "selective pressure on what content should be covered at earlier levels" (Hugo, 2013, p. 61). In essence, Hugo suggests that there seems to be greater consensus on the 'what' that is included in mathematics and science subjects. As Hugo (2013) points out selection criteria is important as the teacher should know what to prepare students to do and where in the rest of the degree or in other modules the content fits in. He points out that the selection of content calls into question whose knowledge and what knowledge is of most worth (Hugo, 2013).

Sequencing of knowledge refers to how knowledge is ordered, that is what knowledge and skills are to be acquired and in what order (what comes before and what comes after). The teacher may have explicit (F+) or implicit (F-) control over sequencing (Naidoo, 2012). If the sequencing of content shows what was taught before the current lesson and what will be taught after, that is, what the current lesson builds on and what it leads to, it is strongly framed. In this case students are not given the opportunity to contribute to how the module is sequenced. In mathematics sequencing is important as it enables development of mathematical concepts from lower levels of complexity to higher levels of complexity and abstraction (Hugo, 2013). Furthermore appropriate sequencing enables students to make logical connections which lead to relational understanding (Krathwohl, 2002; Raths, 2002). Sequencing is viewed as weakly framed when students make an input on which section follows next since they are allowed to affect the sequence of topics. Without proper sequencing principles to guide the progression of content, content and topics become chaotic with little opportunity for students to see where it all leads or how they all fit in. Furthermore, the opportunity to develop higher levels of complexity will be reduced (Hugo, 2013). Hugo explains that,

> a logically ordered and hierarchically structured subject has clear and simple states, links, orders and levels … you can trace the validity of the connections one by one, resulting in a clear, unambiguous trail through each level and between levels [that] … allow for sequences to build upwards in great length, sophistication and complexity. (p. 89)

Naidoo (2012) describes pacing as that which needs to be learned in the specified time. Hugo (2013) describes pacing as strong (or closed) when there is a stipulated time frame within which the task or topic or section must be started and completed and weak (or open) when students are allowed to work at their own pace. He contends that pacing should be based on how 'heavy' the content is rather than the time taken for the students to acquire the knowledge or the designated time stipulated in the curriculum. How 'heavy' the topic is depends on the amount of foundational or background knowledge or competency that is required to understand the current topic. In addition, pacing should consider the topic's relation to future topics or the development of the topic itself as proper sequencing facilitates the acquisition of knowledge and skills in the future. Pacing can be fast and closed, fast and open, slow and closed or slow and open (Hugo, 2013).

Bernstein identified evaluative criteria as being central in specifying the requirements for recognizing and producing the legitimate text (2000). Explicating the evaluation criteria is a central aspect of pedagogic practice (Hoadley, 2006) "to promote higher levels of learning of all students" (Morais, 2002, p. 568). Evaluative criteria play a key role in determining the pedagogic practice that enhances the opportunity for success amongst students (Hoadley, 2006). Strong framing over evaluative criteria results in the evaluative criteria being made explicit thereby facilitating student's production of the legitimate text. The ability to produce the legitimate text is based on acquiring the recognition and realization rules and enables students to realize what is missing from their own answers. Students are expected to acquire specific criteria and to be able to apply it in the course of assessments. Hence recognition and realisation of the evaluative criteria is central to students producing the required text (Morais, 1996).

Clearly defined evaluative criteria can be made explicit through assessments, feedback, marking criteria and corrections (Morais, 1996). Explicating evaluative criteria to students involves "clearly telling children what is expected of them, of identifying what is missing from their textual production, of clarifying the concepts, of leading them to make synthesis" (Morais *et al*., 2004, p. 8). Working on the assumption that teachers mark and correct assessments according to specific criteria, Morais (1996) suggests that providing students with the principles of correction will facilitate student's acquisition of the legitimate text. In marking or correcting student's work, as the evaluative criteria become more explicit, the framing of instructional discourse (ID) gets stronger. Simultaneously, the teacher provides more textual feedback, thereby explicating the evaluative criteria and weakening framing over the regulative discourse (RD) (hierarchical rules). Morais and Miranda (1996) provide a scale for reflecting the framing relations between the ID and the RD. No notation on a student's piece of work means that the evaluative criteria are not explicit thereby depriving students of the opportunity to produce the legitimate text. This scenario implies an imperative/ positional mode of control at the level of discourse. On the other end, if the teacher writes the legitimate text (correction), it reflects personalized communication providing the opportunity for students to self-evaluate increasing their opportunity to produce the correct legitimate text in the future (Morais, 2002). This is reflective of personal control at the level of discourse and a weak framing over RD.
Student feedback is one of the most significant factors in assessment that can be attributed to enhancing student achievement as it provides information on misunderstandings as well as understandings (Hattie (1999). Student feedback can be achieved using formative and summative assessment, tutorials, questioning techniques and instruction. Summative assessment is a useful tool as it has the challenge of ascertaining whether the learning outcomes that have been set out, have been achieved and can assist in planning the way forward in terms of teaching and learning. In addition, feedback has the potential to alert teachers and students to the different milestones that evidence learning, enables the teacher and students to see where they stand in relation to achieving the milestones and to determine appropriate strategies to assist the students achieve the milestones (Hattie, 1999).

Morais (2002) explains that strong framing over evaluative criteria (explicit evaluative criteria) enhance students' opportunities to acquire recognition and realisation rules. Morais makes the point that this combined with weak framing of pacing is beneficial to student learning, Alternatively weakening the classification of intra disciplinary relations will lead students to higher levels of abstraction making their learning more meaningful and creating opportunities for them to constantly revisit the same concept in different sections. She contends that weak classification and framing over pacing, hierarchical rules, knowledge relations and relations between spaces create conditions that are conducive to learning. Be that as it may, this raises the question: Whose learning has the potential to be enhanced and in what contexts will such combinations of classification and framing be successful? Muller (1998) asserts that some of the more 'progressive' curricula which claim to bring about equality and redress have the potential to do the opposite. Two of these progressive curricula which are viewed critically are problem-based and project-based learning. Case (2011), speaking in the context of problem-based and project-based learning, contends that weak classification can potentially disadvantage the working class student as it has consequences for students in that it results in student learning that contradict the aims. She argues that engineering curricula in fact require strong interdisciplinary boundaries to distinguish highly specialized academic knowledge.

Bernstein distinguished between recognition and realization rules explaining that "recognition rules create the means of distinguishing between and so recognizing the speciality that constitutes a context, and realization rules regulate the creation and production of specialized relationships internal to that context" (Bernstein, 1990, p. 15). Recognition and realization rules (at the level of the subject) are a function of the values of classification and framing. Recognition rules are the principles for distinguishing the specialization of the context which means that they specify the principles for recognizing what constitutes the 'legitimate text' and the voice to be acquired (Morais, 1996; Parker, 2005; Bernstein, 2000). Strong classification provides the criteria to demarcate the different categories enabling students to recognize the specificity of the context. This forms the basis for inferring the recognition rules which regulate the orientation to meanings associated with the legitimate text. Since the recognition rules are at the level of the acquirer, classificatory principles create recognition rules which enable the acquirer to orientate to the specific features that distinguish the context (Bernstein, 2000).

Be that as it may, according to Bernstein, 2000), while acquisition of the recognition rules precedes the acquisition of realisation rules, it is no indication of whether students will acquire the realization rule. Realisation rules shape how students put meanings together and how they reproduce the legitimate text. Framing values define context management and pedagogic communication. Different framing values produce different rules for the creation of text and require the acquisition of different realisation rules. Realisation rules provide the principles that regulate the development and production of the internal relations which facilitate the reproduction of the 'legitimate text'. Effectively producing the required legitimate text requires acquiring the particular coding orientation relevant to the given context. The extent of acquisition of the recognition and realization rules can be determined by the extent to which students can reproduce the teacher's criteria, indicating how well the student has acquired the particular coding orientation relevant to a given context (Bernstein, 2000).

Realisation rules are principles that comprise two dimensions: the selection of meanings and the production of the text with respect to the meanings selected. A student who has acquired the realization rules will be able to demonstrate correct selection of meanings and will be able to produce the required text (Morais, 1996). The demonstration of the recognition and realization rules are evidenced by the ability to show 'correct' performance in the given context through the selection of appropriate meanings and the production of the texts. The inability to demonstrate correct performance in the given context is a sign that the subject lacks recognition and/ or realization rules. The lack of realization rules implies the inability to select appropriate meanings or to produce the appropriate text accordingly or both. Realisation rules are regulated by recognition rules. The ability to select appropriate meanings without being able to adequately produce the required text accordingly results in the subject achieving 'passive realisation'. That is they have acquired the ability to select adequate meaning but are not able to follow through with articulating it in the produced text. The ability to produce the correct text reflects 'active realisation'. To illustrate Bernstein's theory, if the pedagogic practice requires students to achieve the competence of co-operation, they would need to: identify the recognition rules; attach meanings to the specific context in terms of what is required to achieve cooperation (passive realization); achieve 'active realisation' through producing the text according to the rules of the classroom and achieving the necessary dispositions (motivations, aspirations, values) toward that realisation.

Bernstein explains that while classification is regarded as the voice of the message and the means to recognize the message, framing provides the means by which to realize and acquire the legitimate message (Bernstein, 2000). Some modalities are associated with strong recognition and realisation rules and others with weak recognition and realisation rules. Strong framing over selection, sequencing and evaluative criteria require acquisition of rules which generate the privileged meanings. Weak framing over the selection, sequencing and evaluative rules, result in a divided, incomplete realization associated with meanings which have been selectively chosen. Morais (2002) claims that for students to produce the legitimate text they must acquire the specific coding of the discourse. The findings from her research show that mixed pedagogic practices based on strong and weak classification and framing can lead students to develop recognition and realisation rules within the context. Her research shows that weak classification and framing over pacing, hierarchical rules, knowledge relations and spaces, with strong framing over selection, sequencing and evaluative criteria create conditions that are conducive to learning. In her research, Morais (2002) examined the interplay between the various characteristic of pedagogic practice and found that while weak framing of pacing with strong evaluative criteria enhances the opportunity for success, weak framing of pacing combined with weak framing of evaluative criteria will not have the same effect. Bernstein argues that weakening the pacing in the long term means providing more time for students to grasp the recognition and realisation rules, a commodity that is relatively expensive. Morais (2002) responds that different modalities of pedagogic practice can work to weaken framing of pacing without increasing the time. One suggestion is to weaken classification over spaces which she says weakens framing over pacing, while simultaneously strengthening framing of evaluative criteria and weakening framing over hierarchical rules. Weakened framing over hierarchical rules creates a conducive environment for students to discuss and question, thereby strengthening the evaluative criteria. The modality of pedagogic discourse that the student is presented with has implications for how students might potentially respond in terms of disposition to the discourse as well as access to recognition and realization rules (Bernstein, 2000).

Evaluative criteria could be performance-based or competence-based. Since the ME module has been established as a region, it is based on the performance model. The performance model emphasizes specific outputs that the acquirer must demonstrate, the text that the student must produce and the particular skills necessary to produce the required text (Bernstein, 2000). The recognition and realization rules regarding the production of the legitimate text are explicit with strong framing over selection, sequencing and pacing. Evaluation focuses on what is missing from the student's production. In other words the performance model demonstrates explicit classification of discipline areas, explicit control over space, time and discourse and what needs to be transmitted and acquired (that is the skills and procedures).

In competence-based assessments learners are evaluated against what they have achieved rather than what is missing or what they have not achieved (Naidoo, 2012).The competence model emphasizes the realization of the competencies that the acquirer is expected to have in place. The recognition and realization rules are implicit with the acquirer (student) having some control over the selection, sequencing and pacing of the content. With the competence model, the focus is on differences rather than stratification. Additionally, classification of spaces is weak and implicit giving students some degree of control over space. Control over space, time and discourse is implicit. Young's criticism of a competence-based curriculum is evident in his remarks concerning 'opening out' the curriculum. He indicates that the danger associated with 'opening out' the curriculum, to one that is more concerned with privileging individual qualities rather than the knowledge itself denies students access to objective knowledge and to the global communities that form the social basis of the knowledge (Young, 2010).

2.4 Vertical and Horizontal Discourse

The concepts of esoteric and mundane knowledge emerged in the work of Durkheim and features distinctively in the work of Bernstein (Sadovnik, 1995; Moore & Muller, 2002). Esoteric knowledge refers to theoretical or conceptual knowledge which transcends contextual knowledge and elevates it to higher levels of abstraction. Abstraction and contextual independence lead to understanding of the nature of relations in the world (Bernstein, 2000). Esoteric knowledge refers to what Bernstein terms vertical discourse (esoteric) which he defines as knowledge of the ‘not yet thought’ or the ‘unthinkable’. This stands in contrast to the concept of ‘mundane’ or horizontal discourse which Bernstein describes as “knowledge of how it is (the knowledge of the possible)” (Bernstein, 2000, p. 157). Bernstein’s concepts of vertical and horizontal discourse are used to analyse the internal principles of knowledge construction, and social relations of the forms of discourse (Bernstein, 1999). The ME module falls within the ambit of vertical discourse. This study analyses the content, pedagogy and assessment in the ME module using Bernstein’s concepts of recontextualisation, singulars and regions and classification and framing.

Horizontal discourse is described as common sense knowledge due to its accessibility to all. According to Bernstein, “a horizontal discourse entails a set of strategies which are local, segmentally organized, context specific and dependent, for maximizing encounters with persons and habitats” (Bernstein, 1999, p.159). It follows from the term ‘segmentally organized’ that what is learned in segments and what is acquired in a segment may have no relation to that acquired in another segment. For example, learning to tie one’s shoelaces is a separate activity from learning to brush one’s teeth where competence in each is acquired separately from each other and showing competence in one is not necessarily related to or influences the acquisition of competence in another. Horizontal discourse is “likely to be oral, local, context dependent and specific, tacit, multi-layered, and contradictory across but not within contexts” (Bernstein, 2000, p. 157). Segments may have unequal distribution of importance, where some aspects of knowledge within this discourse are more highly valued than others (Bernstein, 2000). Horizontal discourse stands in contrast to vertical discourse.

Vertical discourse is defined as abstract, context-independent knowledge and is regarded as the most powerful knowledge that provides access to the ‘unthinkable’ and the ‘yet to be thought’ (Bernstein, 2000). Vertical discourse is described as the discourse which,

> takes the form of a coherent, explicit, and systematically principled structure, hierarchically organised, as in the sciences, or it takes the form of a series of specialised languages with specialized modes of interrogation and specialized criteria for the

> production and circulation of texts, as in the social sciences and humanities. (Bernstein, 1999, p. 159)

Unlike the segmented organization of horizontal discourse, vertical discourse, is reflective of “integration at the level of meanings” and consists of specialized symbolic structures of explicit knowledge (Bernstein, 1999, p. 161). The social units of acquisition in the pedagogy of vertical discourse are “constructed, evaluated and distributed to different groups and individuals, structured in time and space by ‘principles’ of recontextualising” (Bernstein, 1999, p. 161). There is a further differentiation of vertical discourse according to types of knowledge structures. These are distinguished as hierarchical and horizontal knowledge structures.

A hierarchical knowledge structure “takes the form of a coherent, explicit, and systematically principled structure … [which is] hierarchically organized, as in the sciences” (Bernstein, 2000, p. 157). This type of knowledge structure attempts to develop general theories and propositions which enable the integration of knowledge at lower levels while simultaneously illustrating the consistency of the various different underlying phenomena. Characteristic of this hierarchical knowledge structure is the propensity to achieve greater levels of abstraction and integration. Horizontal knowledge structures characteristically comprise a series of specialised languages. There are specific rules for appraising these specialised languages and specific rules for developing and distributing the texts. Horizontal knowledge structures are typically based on collection codes and include disciplines within the humanities and social sciences (Bernstein, 2000). Be that as it may, Hugo (2013) argues that the degree of insulation of a category is not linked to its structure with regard to whether it is hierarchical or horizontal implying that a subject that is hierarchical does not necessarily mean that it needs to be isolated from other modules. He explains that,

> By rigorously specifying in advance what we should expect to see if the theory holds, we can measure the limitations of the theory if we fail to find it or encounter other things unexpected and unspecified. In this way the theory can avoid the circularity that so often characterises (and vitiates) research applications of theories lacking such methodological depth. (Hugo, 2013, p. 368)

2.5 Abstract and Theoretical Knowledge

Bernstein (2000) asserts that a precondition for effective democracy is access to abstract theoretical knowledge. He justifies his claim stating that access to abstract theoretical knowledge provides the means to new possibilities as it would enable one to think the ‘unthinkable’. Wheelahan (2012) supports this as she asserts abstract theoretical knowledge provides the means to determine the nature of relations and to connect the thinkable and the unthinkable which is a precondition for the existence of society. She argues that exposure to abstract theoretical knowledge provides students not just with an understanding of the complexity of a subject, but the ability to develop disciplinary reasoning which will enable them to participate in society’s conversations and debates about “how society should respond to threats such as global warming, … society’s values, norms and mores and questions such as whether the banks need more regulation” (Wheelahan, 2012, p. 2). She positions herself against contextualizing learning, arguing that such an approach displaces abstract theoretical knowledge as a central feature of the curriculum and in so doing deprives the student of access to theoretical understanding of the content. The student is then denied the opportunity to engage in conversations about society and where it is going (Bernstein, 2000), a situation that potentially threatens the achievement of democracy. Access to abstract theoretical knowledge is an issue of social justice, an aspect of redress, which is essential to the achievement of democracy (Wheelahan, 2012). The “importance of knowledge in its own right” (Wheelahan, 2012, p. 1) is sidelined by approaches such as constructivism, technical instrumentalism and traditional approaches which serve to prioritise curriculum objectives and subordinate the role of knowledge.

Young (2009) distinguishes between knowledge of the powerful and powerful knowledge. He says knowledge of the powerful analyses how access to knowledge is mediated and legitimated. It refers to who defines what counts as knowledge linking this role to powerful groups in society. He argues that those in power enable and have access to higher education and certain kinds of specialized knowledge (2009).Young claims that this knowledge refers to the potential for intellectual power that comes with access. Powerful knowledge provides access to more reliable explanations and new ways of thinking about the world. Acquiring powerful knowledge can provide learners with a language for engaging in debates about significant social issues (Young, 2008). Powerful knowledge rather than being the knowledge of those in power or those who legitimate knowledge refers to the power of knowledge in terms of whether it enables trustworthy explanations or, according to Young, *new ways of thinking about the world*. This, according to Young, provides a way of conceptualizing the curriculum in a way that tells us something about the knowledge itself. This powerful knowledge is regarded as specialist knowledge that requires a discipline specialist if higher education is to transmit it. Teacher-student relations must operate under certain conditions to enable the transmission of this powerful knowledge. He makes the point that while context-specific knowledge is necessary in the workplace, theoretical knowledge is also necessary due to the increasing complexity of knowledge demands.

Young (2009) argues that a hierarchical teacher-student relationship is conducive to learning because students lack the prior knowledge necessary to be equal participants in the choice of this knowledge and as such their role in selecting the knowledge should be limited. Furthermore, speaking in the context of schools, he justifies the need for the teacher-student relation to be hierarchical as "authority relations are intrinsic to pedagogy" (2009, p. 14) although not dismissing the importance of the knowledge that the student brings to the classroom. I believe that Young's views can be extended to the higher education context, more specifically the ME module as my study indicates that the knowledge that students bring to the classroom is often regarded by lecturers as inadequate. This requires an examination of the relations between the disciplines of mathematics and engineering (inter discursive relations).

Young (2009) distinguishes between context-dependent and context-independent knowledge, describing the former as that knowledge which is not generalisable. This means that the skill or knowledge is grounded in the context of the problem. He exemplifies context-dependent knowledge using two examples which I draw on to illustrate his point: the first is the example of learning how to repair a mechanical fault and the second is finding a route on a map. Bernstein (2000) describes context independent knowledge as knowledge that is theoretical and abstract and that leads to generalizations and universal claims. This context independent knowledge is referred to as powerful knowledge that is meant to lead to "new ways of thinking about the world" (mentioned earlier) and that provides justifiable explanations of the world.

Young acknowledges that while it is the goal of schools to provide the powerful knowledge, it might not always be successful in achieving this. Students who come from elite cultural backgrounds have a greater opportunity to be successful as their background is more congruent with that needed to be successful in acquiring ‘powerful knowledge’ than those who come from a disadvantaged background. The question then posed by Young asks whether the curriculum is “a means by which pupils can acquire powerful knowledge”? (2009, p. 15) and suggests that students from disadvantaged backgrounds require active participation in the educational context if they are to have the opportunity to acquire the powerful knowledge and to develop intellectually. He argues that building the curriculum around the experience of disadvantaged students does them a disservice by limiting them to that knowledge (Young, 2009).

Having presented a discussion of Bernstein’s theories as they relate to this study, it is appropriate to present a balanced view of the framework by discussing some criticisms and professed shortcomings and rebuttals of the parts of Bernstein’s work relevant to this study. These are dealt with in the following section.

2.6 Development of Bernstein’s theories

The notions of deficit and difference have been identified as major criticisms in Bernstein’s work on code theory (Singh, 1997). His rejection of the deficit-difference debate is supported by his argument that code theory attempts to explain why middle class students perform better educationally than working class students in the same educational context. In attempting to explain the disparity in educational performance of the different groups of students, code theory provides an explanation of how family structures and processes are connected to educational structures and processes (Sadovnik, 2001). This is exemplified in the following quote from Bernstein (1990):

> The code theory asserts that there is a social class regulated unequal distribution of privileging principles of communication … and that social class, indirectly, effects the classification and framing of the elaborated code transmitted by the school so as to

> facilitate and perpetuate its unequal acquisition. Thus the code theory accepts neither a deficit nor a difference position but draws attention to the relations between macro power relations and micro practices of transmission, acquisition and evaluation and the positioning and oppositioning to which these practices give rise. (p. 118-119)

Singh's defense of Bernstein is summarized in her review essay of Bernstein's paper titled: *Pedagogy, symbolic control and identity*, where she claims that the critique of Bernstein's work is erroneous and arose out of a misconception of the terms 'restricted' and 'elaborated' code. Her argument is that critics understood the term 'restricted', as a fundamental difference between the working and middle class, rather than as a description of "learned forms of language use complexly caught up in relations of class power in educational institutions" (Singh, 1997, p. 2).

Bernstein's work is also criticized for his explanations of structuralism which critics claim lack human agency. When compared to the work of Bourdieu (1990) the sentiment was that Bernstein's work was more flexible in its approach to the problem of structure and agency (Sadovnik, 2001) than Bourdieu's. There is also criticism of some research based on Bernstein's theories for example if the theory comes before the research it removes the potential for the theory to undergo change. This creates the perception that data is generated and made to fit neatly into categories that are already pre-determined (Ensor & Hoadley, 2004). These researchers commented: "It would appear, from the criticisms made, that we enter the field with categories shaped rather like containers, into which we scoop our data" (p. 97). Despite this, Ensor and Hoadley argue that analysis actually paves the way for theory development as exemplified in Hoadley (2006). Moore and Muller (2002) explain the value of Bernstein's theory in potentially circumventing the circularities that concern critics. Bernstein says that the rules,

> must be capable of realising all empirical displays to which the context gives rise. This is crucial if circularity is to be avoided; in which case the theory constructs at the *level of description* only that which lives within its own confines. Thus the principles of description, although derived from the theory, must interact with the empirical contextual displays so as to retain and translate the integrity of the display. Thus the principles of description are the key principles in bringing about a dynamic relationship between

> theoretical and empirical levels...Thus a theory is only as good as the principles of description to which it gives rise. (Bernstein, 2000, p. 91)

While Bernstein's theories and models offer a tool for analyzing the structure and organization of the three message systems, they do not speak to the quality of the same (Bertram, 2008). Bertram found that to determine the conceptual level of questions posed in lessons and evaluation, she had to look to other frameworks that would provide the qualitative clarity. Bernstein contends that evaluation condenses the entire meaning of the pedagogic device. I therefore found it necessary and of relevance to this study to investigate the quality of teaching and learning. Considering that the pedagogic device culminates in evaluation, the analysis of the quality of assessments would evidence this. As Bernstein's theory falls short on determining the quality of assessment, as with Bertram (2008), I looked to another analytical framework that would enable me to analyse the quality of assessments. This analytical tool was found in Bloom's revised taxonomy, the analytical tool employed by Bertram (2008) to analyse the quality of assessments.

The claim that Bernstein's work was not empirically tested is countered by his sociological theory of pedagogy which presents the researcher with a highly systematic account of how pedagogy works. The theory is worked out with a rigour and precision that gives rise to an array of inter-related concepts that have a delicacy and 'methodological depth' which is extremely useful to the researcher. However, Bernstein's theoretical categories do not allow for a direct reading of the empirical: a language of description is needed, and a significant amount of work needs to be undertaken in order to bring the concepts closer to the data for its reading. In this study I illustrate an instance of where such work was done, in relation to the conceptual category framing. I also reflect on some of the difficulties raised earlier in working with the concept.

Bernstein has been accused of having a writing style that is difficult to understand, dense and incomprehensible (Sadovnik, 2001). However Bernstein's acknowledgement of this critique is addressed through the inclusion of illustrative examples in the revised edition of *Pedagogy, symbolic control and identity: theory, critique and research* (2000). From my reading of the revised edition, I found that the concerns about the writing style were addressed as his book made for easy reading without compromising the quality of the material presented.

Despite the criticisms, Bernstein provides an analytical framework from a sociological perspective that provide an explanation for why middle class students perform better than working class students in equal educational settings. The value of his work and applicability more especially in the South African context outweigh the inadequacies alleged by critics of his work.

2.7 Teachers Philosophical and Epistemological Conceptions

Mathematics means different things to different people and this is evidenced in how it is taught and what influences how it is taught (Holton, 2001). Deciding how to teach mathematics to future engineers may be influenced, either tacitly or overtly, by academics' experiences or beliefs about the nature of mathematics, teaching and learning mathematics to engineers and the institutional context (Mason, 2001). One of the aims of this study is to ascertain the philosophies that mathematicians have of mathematics and to determine to what extent this influences their approach to teaching and learning mathematics to future engineers. Drawing from the literature, the dominant views of mathematics are summarized in Table 2.2 together with identifying factors associated with each. Following this is an elaboration of the instructional approaches that are associated with each of these views of mathematics. The different views of mathematics are evident in how lecturers conceptualise mathematics for engineers. Each of these views if translated into practice is associated with certain behaviours.

Table 2.2

Identifying Characteristics of the Four Basic Beliefs

Mathematics is ...	
Absolutist	**Formalist**
A body of facts that exists independently of human knowledge Non-changing and a definite answer A static unified body of truths A deductive process	Independent of the experienced world seen as abstraction, logic and rigour Precisely defined symbols with explicit formal proof and rigorous axiomatic procedures An academic activity
Instrumentalist/ algorithmic	**Fallibilist**
Collection of unrelated facts (compartmentalised) Rules and skills used when attempting to find solutions to problems that are outside of the subject Single correct answer	Body of knowledge that is constantly growing and changing Potentially flawed and open to revision and correction A result of human endeavour Developed through social constructivism and problem-solving

The predominant modes of instruction arising from the dominant views are summarised in Table 2.3. The absolutist teacher adopts a teacher-centred approach and views teaching as the transmission of knowledge. The teacher and textbook are viewed as the mathematical authorities with the textbook being the authority on what is correct or acceptable as a solution or procedure. The instrumentalist teacher focuses on the mastery of mathematical skills, adopting a mode of instruction that would include: clear, precise instructions, neatly illustrated steps involved in the procedure or solution of a problem and an emphasis on drill and memorisation. Formalist teachers see mathematics as having a logical underlying structure and takes pains to demonstrate this as they teach. They emphasise and explain the rationale behind mathematical rules and procedures. The fallibilist teacher is envisaged as a facilitator whose responsibility it is to develop a learning environment that encourages the construction of knowledge and understanding of mathematical concepts. Teachers in this view encourage discussion among

Table 2.3

Characteristics of Different Views of Teaching and Learning

Absolutist	**Formalist**
Teacher is the authority and source of mathematical truth Following rules and procedures leads to the correct answer Work toward a single correct answer	Teacher takes pains to demonstrate the underlying logical structure of mathematics Emphasis on formal geometric proofs
Instrumentalist	**Fallibilist/ social constructivist**
Emphasises teacher as authority and taking notes Teaching rules without explanation Demonstrates procedures that students must use Encourages students to memorise and practice procedures and computation	Encourages students to question and think Encourages students to participate in their own learning Effort to build student understanding Encourage students to make conjectures and reason out solutions to problems

students and between students and lecturer, follow up on student's ideas and encourage students to ask and answer questions. Students are seen as active participants in their own learning and constructors of knowledge through guided discovery, social interactions and discussion.

Kent & Noss (2000) question whether mathematicians and engineers should have the same epistemological approach to mathematics. He argues that the perspectives that designers of technology hold depends on their understanding of mathematics and its functions. This foregrounds the need to determine the understandings that lecturers hold about mathematics for engineers in the ME module and how it is taught and learned at the SAHEI.

2.8 Bloom's revised taxonomy

In this study the analysis of assessments was conducted using Bernstein's concepts of classification and framing. While this could provide some insight into how strongly the evaluative criteria were explicated, it could not speak to the quality and complexity of the assessments. A tool that addressed this concern was found in Bloom's Revised Taxonomy. The paradigmatic orientation to this study is pragmatism, an orientation which embraces multi method research. So, while I acknowledge that the approach to aspects of this study took a sociological stance, I found that it was not sufficient in addressing the issue of quality which critics pointed out was missing in Bernstein's theories. Following the pragmatic stance I searched for a tool that could analyse the quality of assessments. In my reading of the literature, I came across the work of Carol Bertram who used Bloom's taxonomy in studies that also used Bernstein as a theoretical framework (Bertram, 2008). Bertram's work provided much clarity on how such a combination of Bernstein and Bloom would enhance the research. I found the use of the revised taxonomy useful to illuminate the construct being analysed and notwithstanding its psychological base, embraced its use in this research.

Bloom's revised taxonomy is an enhanced version of the original taxonomy. In keeping with Krathwohl (2002) Bloom's Revised Taxonomy is referred to as the 'revised taxonomy' in this thesis. The revised taxonomy depicts a broader vision of the original taxonomy in terms of the acquisition of knowledge and the capability of using it in diverse new situations.

Raths (2002) suggests that the new taxonomy can be used to align activities and assessments with the goals of the module as well as to improve learning and instructional goals. Aligning goals, pedagogic practice and assessment provides the opportunity to enhance teaching and learning (Raths, 2002). Bernstein contends that the aim of the pedagogic device lies in assessment. The revised taxonomy thus provides the opportunity for assessment to focus on learning (Airasian & Miranda, 2002). In this study, the revised taxonomy is used to analyse the quality of assessments in terms of the level of cognitive demand of additional tutorials, mock assessments and assessments. The revised taxonomy functions on four dimensions; factual knowledge, conceptual knowledge, procedural knowledge and meta-cognitive knowledge.

Factual knowledge denotes the fundamental knowledge that students must master to be acquainted with a discipline or to be able to solve problems. Conceptual Knowledge refers to knowledge of the relationships among the key elements which enable them to work and to work together. Procedural Knowledge refers to knowledge about how to use algorithms, techniques and methods. Meta-cognitive Knowledge indicates an awareness of one's own cognition and thinking.

The cognitive process dimension has six categories which are, in hierarchical order: *remember*, *understand*, *apply*, *analyse*, *evaluate* and *create*. These are explained in Table 2.4 The level of Understand is achieved when the student is able to build connections between existing and new knowledge. Skills that count as evidence at this level include interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining. The level of Apply on the revised taxonomy is associated with procedural knowledge, and is demonstrated in executing (familiar problem) and implementing (novel problem). Execution is the application of a procedure for example, learning how to divide two double digit numbers and doing 15 problems of practicing this procedure, whereas implementation requires understanding the knowledge sufficiently to be able to apply it to new situations (Mayer, 2002).

On the level of *Analyse,* the student demonstrates higher order cognitive functioning. A concept is divided into constituent parts with the aim of understanding how each part works and how they all work together. Achievement at this level is evidenced by the student being able to differentiate, organise an attribute. The *Evaluation* level requires the student to make judgments based on criteria. The indicators at this level include checking (coordinating, detecting, monitoring or testing) and critiquing (judging). Checking refers to assessing the internal consistency whereas critiquing looks to finding external consistency. On the level of *Create* the student is able to demonstrate the ability to develop an original 'whole' from various components. The activities associated with the level of *Create* are generating, planning and producing.

Each level on the revised taxonomy can be further qualified according to the levels of knowledge. They range from the simple to the complex and are: factual knowledge, conceptual knowledge, procedural knowledge and metacognitive knowledge. So, for example, a test item might require remembering factual knowledge which is less demanding than remembering a procedure.

Table 2.4

Structure of the Cognitive Process Dimension of the Revised Taxonomy (Krathwohl, 2002)

Level	**Description**	**Characteristics**
Remember	Retrieving relevant knowledge from long-term memory	1.1 Recognizing 1.2 Recalling
Understand	Determining the meaning of instructional messages, including oral, written, and graphic communication.	2.1 Interpreting 2.2 Exemplifying 2.3 Classifying 2.4 Summarizing 2.5 Inferring 2.6 Comparing 2.7 Explaining
3. Apply	Carrying out or using a procedure in a given situation.	3.1 Executing 3.2 Implementing
4. Analyze	Breaking material into its constituent parts and detecting how the parts relate to one another and to an overall structure or purpose.	4.1 Differentiating 4.2 Organizing 4.3 Attributing
5. Evaluate	Making judgments based on criteria and standards.	5.1 Checking 5.2 Critiquing
6.Create	Putting elements together to form a novel, coherent whole or make an original product.	6.1 Generating 6.2 Planning 6.3 Producing

Using the two-dimensional taxonomy table, mathematical tasks can be evaluated according to level of cognitive demand and the type of knowledge required in solving the problems (Krathwohl, 2002). For each category of knowledge, I looked for indicators that allowed me to identify what counts as evidence for each level according to the structure of the revised taxonomy. These were then recorded in the two-dimensional taxonomy table. The mock and final examination papers were analysed to determine the cognitive demand of the problems that students were given. This enabled me to determine the level of cognitive development that the teaching and learning approach aimed to achieve thereby addressing the question of quality of the examination.

2.9 Conclusion

In this chapter, Bernstein's theory of the pedagogic device was presented and the concepts of recontextualisation, regions and singulars and classification and framing were explained. Bernstein's theories and concepts provided the framework for the interrogation of the role of mathematics in engineering (as seen in the structure of the module) and the approach to teaching and learning (transmission and acquisition as seen in the pedagogic practice) in the ME module in this study. An interrogation of the pedagogic device shed light on how knowledge is recontextualised from the field of production to the lecture room. A discussion of singulars and regions provided an understanding of the tension and struggle around the ME module. The concept of classification was used to explain how boundaries serve to restrict or constrain the acquisition of recognition rules while framing provides the means of acquiring the realisation rules which enable the students to put meanings together and to reproduce the legitimate text. Framing establishes the message and regulates the realisation rules that produce the discourse.

Bernstein's explication of the pedagogic device is of importance in this study as it foregrounds understandings of or the assumptions about knowledge and their impact on pedagogical practice. It is considered an appropriate framework for a study that seeks to understand how teaching and learning are approached. Bernstein contends that pedagogic discourse is a carrier for hegemony allowing patterns of dominance to reign. South Africa has identified transformation in higher education as a national concern making the SAHEI a medium for change. The ME module while constituted by the department of mathematics is positioned within the engineering curriculum and is thus a site for appropriation, conflict and control. This study aims to draw out the interplay between the disciplines of mathematics and engineering with regard to the classification and framing of the ME module. Furthermore, the concept of beliefs was used to explore reasons why the established teaching and learning approaches were adopted while Bloom's Revised Taxonomy was used to evaluate the quality of the questions in the final examination.

The following chapter, Chapter Three, presents a review of the literature pertaining to teaching and learning mathematics from the perspective of science and engineering and some studies that have been conducted nationally and internationally using Bernstein's concepts of the pedagogic device and the concept of beliefs.

Chapter Three
Teaching and Learning Mathematics

This chapter has two parts. Since the focus of this study is a mathematics module within an engineering curriculum, the first part of this chapter is organised by the salient aspects of this module, namely lecturer pedagogy, student learning, and assessment. Since it is argued that lecturer's pedagogy is strongly influenced by their personal philosophical and epistemological conceptions of mathematics, different perspectives on the nature of mathematics are presented and discussed. This is followed by a presentation of two seemingly disparate views of teaching which nevertheless provide a starting point to a more nuanced discussion of teaching informed by a Bernsteinian conceptual framework. Lecturer pedagogy is contextualised within a wider discussion of current trends in mathematics to future engineers, particularly in the selection of mathematical content. Second, a review of the different approaches of students to their learning is presented and related to the pedagogical approaches taken by the lecturers. Third, following the contention (Bernstein, 2000) that evaluation condenses the pedagogic device and hence assessment is the culmination of teaching and learning, the first part of this chapter concludes with a discussion of assessment and the factors that influence student success in the assessment. The second part of this chapter is a review of similar studies nationally and internationally, using Bernstein as a framework.

This study set out to understand how teaching and learning mathematics is approached in the engineering curriculum at a SAHEI. The first research question seeks to establish the role of mathematics in engineering at the SAHEI. The second research question seeks to determine how teaching and learning in terms of the content, pedagogy and assessment is approached at the SAHEI while the third looks at why academics approach the curriculum the way they do. The next section begins with a discussion of the various understandings of the term 'curriculum' and establishes a definition of the term as used in this study.

3.1 Curriculum

As the term curriculum often has varying meanings attached to it, a brief summary of some understandings of the term are provided. The summary is used to formulate a working definition of the term curriculum for the purpose of this study. Bernstein's definition of the term curriculum refers to the content (or knowledge), pedagogy and assessment that is included in a discipline, subject or module (Bernstein, 2000). In the National Education Policy Investigation report (NEPI, 1992), the term curriculum refers to activities and encounters that fall within the realm of teaching and learning. The South African Qualifications Authority (SAQA) in a discussion paper introduces a philosophical dimension to its definition of 'curriculum' which is "the philosophical and organisational framework for a specific curriculum" and includes all facets of teaching and learning (South Africa Qualifications Authority, 2001, UNISA, 1996, p.17; Nkomo, 2000). Similarly, the Curriculum Framework for GET and FET described the term curriculum as encapsulating all activities associated with teaching and learning, such as learning, assessment, methodology and learning programmes (Department of Education, 1996) while McDonald and Van Der Host (2007, p. 3) refer to curriculum as all aspects relevant to teaching and learning where the aspects considered integral to the programme of study are content, outcomes, methods, and assessment procedures. With the exception of Bernstein, the common characteristics of the term curriculum arising out of the descriptions listed above, embrace all facets of teaching and learning which include the content, pedagogy and assessment with some authors incorporating in the definition, the paradigmatic underpinning of the teaching and learning approach.

UNISA declares that understanding the curriculum in a discipline includes identifying the paradigms that underpin how teaching and learning is approached. In addition, curriculum development should take account of learning theories, contextual factors and the profile of the intended student population in a discipline (UNISA, 2006). This is supported by McDonald and Van Der Host (2007) who leaning towards a constructive alignment approach (Biggs, 1992), assert that the components of the curriculum, that is, lectures, tutorials and assessments, should be viewed in terms of how they align with the intended outcomes of the module to ensure that they act in harmony with each other in supporting student learning. Drawing from the literature, the operational definition of the term curriculum, within the context of this research, refers to the formal teaching and learning activities that support student learning, more specifically the content, lectures, tutorials and assessments. The next section offers an overview of teachers' philosophical and epistemological conceptions and their influence on teaching and learning.

3.2 Teachers Philosophical and Epistemological Conceptions

The philosophical and epistemological conceptions of the teacher inevitably play an important role in the mathematical learning of their students. The role that they play can have a significant impact on student learning. This is captured succinctly in the following statement:

> There is no doubt that teachers play an important role in the learning of mathematics by their students. However the specific ways in which teacher's understandings, attitudes and characteristics affect their students is not widely understood. In fact there are widespread misconceptions, not only on the part of lay people but also those of mathematics educators, about the ways in which teachers affect the mathematics learning by their students. (Begle, 1979, p. 27)

Conceptions of mathematics carry with them particular epistemological views of mathematics and influence in implicit ways how mathematics teaching and learning is approached (Ernest, 1996; Kuhs & Ball, 1986; Steiner, 1987). This motivates the need to identify the specific characteristics that define a teaching approach and so reinforces the need for a theoretical discussion of teachers' personal beliefs about mathematics, mathematics teaching and learning and their own influences on teaching and learning. First, I clarify the meaning of 'beliefs' within the context of this study to provide a common understanding of the term. Various authors have used terms such as 'philosophy', 'conception', 'perception' and 'world view' to denote what I refer to in this study as beliefs. In my discussion, I maintain the use of the terms as used by the respective authors since I regarded them as synonymous with the meaning that I have attached to the term beliefs. A summary of the conceptions of prominent scholars in the field of beliefs is presented below.

Schoenfeld's initial explanation of the term belief was "one's mathematical world view" (Schoenfeld, 1985, p.45), an explanation that he subsequently clarified as "an individual's understandings and feelings that shape the ways the individual conceptualises and engages in mathematical behaviour" (Schoenfeld, 1992, p. 358) and again as "mental constructs representing the codification of people's experiences and understandings" (Schoenfeld, 1998, p. 19). Drawing on Schoenfeld's initial definition of the term beliefs, Törner and Grigutsch's (1994) description of beliefs is a 'mathematical world view'. Ponte (1994) describes beliefs as 'personal truths' that all people hold which arise from experience and imagination.

3.2.1 The nature of mathematics. Hersh suggests that an "unrecognized cause of failure amongst students is the misconception of the nature of mathematics" (1997, p. xii). From the literature, the teaching by transmission and student-centred perspectives emerge as two extremes on the continuum describing the nature of mathematics (Ernest, 1991). These two perspectives resonate with the absolutist and fallibilist epistemologies respectively. If epistemology is viewed as a continuum, the absolutist epistemology which sits on one extreme end of the continuum, views mathematics as a static, external body of knowledge that espouses the notion of mathematics as certain and absolute (Von Glasersfeld, 1995) and is based on the underpinnings that mathematics is universal and flawless (Lerman, 1983). Hersh's description of the platonist mathematician closely resembles that of an "empirical scientist" who,

> can't invent because everything is already there. He can only discover. Our mathematical knowledge is objective and unchanging because its knowledge of objects is external to us, independent of us, which are indeed changeless. That's what's special about math. There are right answers. Not right because that's what the teacher wants us to believe. Right because they are right. (Hersh, 1997, p. 11)

This view asserts that mathematics exists independently of humans and is discovered as opposed to being created. This view aligns with what Bernstein (2000) refers to as strong classification of knowledge.

On the other extreme end of the continuum, the fallibilist epistemology views mathematics as a body of statements that are open to human error and correction (Ernest, 1991). In this epistemology mathematics is viewed as a changing body of knowledge and the world cannot be known with certainty as there is no certainty in knowledge (weak classification of knowledge). In a similar vein Lerman (1983) claims that mathematics developed as a result of proofs, conjectures and refutations that led to the acceptance of uncertainty as an inherent quality of mathematics. Burton's (1984) expression of this dichotomy resonates with the philosophical clash mentioned by Polya (1981) between mathematics as information and mathematics as know-how. The mathematics as information stance seems to be equivalent to that of the traditional philosophy while mathematics as know-how closely matches that of the progressive philosophy. Polya asserts that,

> our knowledge about any subject consists of information and of know-how. If you have genuine bona-fide experience of mathematical work on any level, elementary or advanced, there will be no doubt in your mind that, in mathematics, know-how is much more important than mere possession of information. (Polya, 1981, xi)

In summary, two dominant approaches to teaching are the transmission and student-centred approaches which resonate with the traditional and progressive approaches to teaching.

Resnick (1988) differentiates between mathematics as an ill-structured discipline and mathematics as a well-structured discipline. She claims that the view of mathematics as an 'ill-structured' discipline suggests that it can have more than one interpretation (weak classification). Consequently mathematics must "have some reference as numerical expressions refer to numbers or abstract entities which, in turn, stand in some regular relationship to actual, physical quantities or enumerable events" (Resnick, 1988, p. 5). This perspective draws many parallels with weak classification and framing. Mathematics as a well-structured discipline displays a clear *hierarchy of knowledge*, with a restricted range of possible answers using agreed upon "postulates and transformations" which are not subject to interpretation or debate (Resnick, 1988, p. 2). Mathematics, in this view, is presented as strongly classified and framed. This approach teaches students that there are specific rules for specific types of problems which will enable them to find ‘the’ correct answer. Students, who approach mathematics in this way, potentially forego the opportunity to develop conceptual understanding and engage in meaningful learning (Resnick, 1988).

Dionne (1984) identified the following ‘perspectives’ of mathematics: (a) mathematics from a traditional perspective as a set of skills; (b) mathematics from a formalist perspective in terms of logic and rigour and (c) mathematics in terms of a constructive process which aligns to the constructivist perspective. Corresponding with Dionne, Ernest’s (1991) initial views of mathematics are briefly listed as: instrumentalist, platonist and problem-solving. Törner and Grigutsch (1994) similarly identified three ‘aspects’ of mathematics corresponding to that of Dionne(1984) and Ernest (1991) and added a fourth dimension to complete the set: the toolbox; process; system and application aspects.

The four dominant views that arose out of the literature are the absolutist (very strongly classified), formalist (strongly classified), instrumentalist (weakly classified) and fallibilist (very weakly classified) views which aligned with the teaching by transmission and progressive views. The absolutist and fallibilist views were discussed earlier in this section while the instrumentalist and formalist views were discussed in Chapter Two and are reiterated here. Instrumentalist teaching centres on the acquisition of mathematical skills and the mode of instruction demonstrates step-by-step procedures that lead to the solution of a problem and promote memorisation. According to Burton (1984) the instrumentalist view makes it difficult to visualize how a transmission-of-information-type classroom can nurture the development of know-how. The result of the failure to develop know-how in mathematics is students who are dependent on mathematics ‘authority’ (lecturer), competitive and answer-driven (Burton, 1984). Skemp (2006) points to four situational factors that contribute to instrumental teaching two of which are the high volume of work and the influence of assessment which is ultimately the goal that students are working to achieve. Formalist teaching views mathematical concepts as independent of the world that is experienced, involves abstraction, logic and rigour with explicit formal proof and rigorous axiomatic procedures. This view results in teaching which ensures that the rationale behind mathematical rules and procedures are explained. One of the consequences of formalist teaching are students who come to believe that mathematics is a compilation of rules, who cannot apply the mathematical knowledge learned to problem solving situations and who fail to link mathematical content to conceptual understanding. Fox (1984) provides an alternate theory of teaching and learning which is discussed next.

Fox (1983) distinguishes between simple theories and developed theories. Simple theories are further classified into the transfer theories and shaping theories and are in line with traditional notions of teaching and learning. Developed theories which are in line with constructivist notions of teaching and learning are classified as growing theories and travelling theories. Teachers who adopt the transfer theory of teaching view teaching as the process of transferring knowledge to students while overlooking whether they have actually received it. Fox's metaphor describes teaching as 'filling the cup' and student failure is ascribed to 'leaking' cups, implying student deficit. However Fox asserts that what the teacher does not consider is that there could be a mismatch where the teaching style may not be conducive to the learning styles of all students. The student who does not perform well is then viewed as unmotivated, lazy and unintelligent (Fox, 1983). Teachers using the shaping theory attempt to 'shape' students into a 'mould' of what they envisage the students to be. They will demonstrate to students how to solve the problems and provide similar problems for students to practice using the method demonstrated. This theory views the teacher as authority and as having absolute control over the lecture. Developed theories are classified into travelling theories and growing theories. Travelling theories view the teacher as a guide and teaching as sharing experiences and providing the opportunity for students to explore. This means that education is viewed as a journey, not a destination. This 'journey' will take the student across many terrains. The growing theory acknowledges that the student has an existing knowledge base and learns in different ways. Thus students are participants in the learning process with different assistance provided to students according to their needs (Fox, 1983).

3.2.2 Influence of teachers' philosophical and epistemological conceptions on teaching and learning. The vast literature on teacher beliefs indicates that it is a well–researched area with some research showing that beliefs are highly influential in teachers' instructional practices as well as in their assessment of students (Borko, Mayfield, Marion, Flexer & Cumbo, 1997; Cooney & Shealy 1995; Fennema & Nelson 1997; Kaplan, 1991; Perry, Howard & Tracy, 1999; Peterson, Fennema, Carpenter & Loef, 1989). Hersh (1997) posits that mathematicians possess different ‘philosophies’ of mathematics which often manifest in their approaches to teaching:

> One’s conception of what mathematics is affects one’s conception of how it should be presented. One’s manner of presenting it is an indication of what one believes to be most essential in it. The issue, then, is not, What is the best way to teach?, but, What is mathematics really all about? (Hersh, 1986, p. 13)

Teachers’ approaches to teaching mathematics reflect the beliefs that teachers’ hold and how these influence the models of teaching and learning that they engage in (Ambrose, 2004; Foss, 2000; Raymond, 1997; Stipek, Givven, Salmon & Macgyvers, 2001). According to Loucks-Harsley *et al*. (2003, p. 7), “beliefs shape ones’ way of perceiving and acting … they shape goals, [and] drive discussion”. These beliefs are at the core of what they conceive as being the nature of mathematics and are thus important in understanding why teachers approach teaching and learning the way they do since “in particular, the observed consistency between the teachers’ professed conceptions of mathematics and the way they typically presented the content strongly suggest that the teachers’ views, beliefs and preferences about mathematics do influence their instructional practice” (Thompson, 1984, p.85). These views reinforce the notion that mathematics teaching is influenced by teachers’ beliefs about mathematics and that personal beliefs about teaching are constructed from our experiences of being taught mathematics and strongly influence our teaching style (Timmerman, 2004).

Be that as it may there is also much evidence that points to inconsistencies between lecturers’ professed epistemology and practiced instruction in lectures so that there is a mismatch between teachers’ espoused and enacted beliefs (Boaler, 2000; Burton, 1988; Hoyles, 1992; Skott, 2001). Burton labels this as epistemological confusion, suggesting that there might be other explanations for why this inconsistency fails to resolve itself.

The constructivist educator uses teaching and learning approaches that promote meaningful experiences. Teaching approaches that encourage interpretation and construction of meaning are more likely to develop students who are good mathematical problem solvers (Resnick, 1988). Lampert suggests that mathematicians come to know mathematics through a "process of 'conscious guessing' about relationships among quantities and shapes, with proof following a 'zig-zag' path starting from conjectures and moving to the examination of premises through the use of counterexamples or 'refutations' " (Lampert, 1990, p. 30). Be that as it may, she asserts that the student experience of 'doing' mathematics in the classroom is vastly different from that of mathematicians as generally 'doing' mathematics means following the rules specified by the teacher (Lampert, 1990).

Traditional teaching claims that mathematics is best learned through transmission of information from the expert (teacher) to the student and assessed through objective, written tests that focus on the reproduction of skills and knowledge. The student is envisaged as someone who seeks certainty, clear explanations, definitions and singular answers from the expert (lecturer). In line with this Lampert claims that students commonly come to know mathematics through a process of following the rules specified by the teacher and that student success is measured by their ability to apply the correct rule. The correct answer or, in Lampert's words, 'mathematical truth', must be authenticated by the teacher who is viewed as 'the authority' (Lampert, 1990, p. 32).

The discussion above highlights the need for university teachers to understand the teaching and learning environment and the nature of the subject (Prosser & Trigwell, 1999). In the light of this, a discussion of theories of teaching and learning follows.

3.3 Theories of Teaching and Learning

Whilst transmission and student-centred approaches to teaching and learning dominate the literature, a third approach considers educational systems from the perspective of the sociology of education, and interrogates the content, pedagogy and assessment. Bernstein's sociological approach to the analysis of the curriculum does this.

3.3.1 The traditional view of teaching (Strong framing over pedagogy). The traditional view of teaching is associated with a teacher-centred approach and perceives teaching as the transmission of knowledge. This view of teaching is also regarded as teaching by imposition. The pedagogical strategy associated with this view is to find ways to assist students to receive or acquire the knowledge that has been transmitted by the teacher (Koehler & Grouws, 1992). This view is based on the assumption that meanings are embedded in the words and actions of the teacher in the environment (Cobb, 1988). In the transmission approach, the teacher assumes responsibility for students' learning by determining all aspects of the teaching and learning process including what will be taught, how it is to be taught, sequence of topics, pace of the lessons and assessments. Consequently this deprives students of the opportunity to take responsibility for their own learning. This approach portrays the teacher as having strong control over the pedagogic process and can be paralleled with what Bernstein categorises as strong framing over selection, sequencing, pacing and evaluative criteria.

This model has its own set of advantages and disadvantages depending on the individual's perspective of teaching and learning. Traditionally teaching by transmission has been a time-efficient way to deliver large volumes of fundamental knowledge to engineering students (Dickens & Arlett, 2009). In an environment where workloads are heavy, assuming this approach to teaching and learning allows teachers to easily deliver large volumes of predetermined content in what are deemed 'easily-digestible' pieces, resources, handouts and activities. It is therefore less time-consuming to teach by transmission. According to Grossman (1986), in the teaching by transmission scenario students are viewed as passive learners and are encouraged by an approach that promotes retention and repetition of content, mastery of skills, memorization of rules, procedures formulae and facts. Having acknowledged that, it has been pointed out that learning through transmission has been noted to have several negative consequences. Firstly, students' ability to apply what has been learned to new situations is reduced. Secondly there is little relevance to the real world and students are deprived of the opportunity to make connections between existing and new knowledge that would make the new knowledge more meaningful. Thirdly it leads to a decrease in the longevity of knowledge retention. Fourthly it deprives students of developing divergent and creative thinking as although learning by rote is a construction in itself, when it is encouraged as the only means of learning it denies students the opportunity to think and learn in a meaningful way (Grossman, 1986). Finally it is pointed out that all students might not respond equally to the teaching by transmission approach hence some students will inevitably be disadvantaged over others.

Dickens & Arlett (2009) contend that the quality of student learning is dependent on the quality of instruction provided and that if students are encouraged to be passive recipients of knowledge it could result in the failure to benefit from the learning experience. They claim that this has motivated changes in the way lectures are presented from traditional lecture format to approaches that provide more opportunities for student participation. The teaching as transmission approach tends to promote a reward system that values grades over personal motivation for success. Students who grasp what is required perform well but will not necessarily be able to apply what they have learnt. Engineering is a vocational profession that demands knowing when and where to effectively apply knowledge. A traditional, transmission approach may not necessarily provide the opportunity for the development of skills necessary to determine when and where to effectively apply knowledge.

Be that as it may, it can be argued that teaching by instruction in itself is an effective approach to teaching and learning. Two goals central to education are retention and transfer where retention refers to students' ability to recall information in a similar way that it was presented (Mayer & Wittrock, 1996) while transfer refers to students' ability to recall, make sense of and be able to apply what they have learned (Bransford, Brown & Cocking, 1999; Mayer, 1995). Mayer (2002) asserts that rote learning enables students to acquire relevant knowledge but not necessarily to transfer it to new situations as the focus is on knowledge acquisition (1999). Mayer makes the point that rote learning is a form of learning in itself and is necessary for meaningful learning to occur as the knowledge is used when solving more complex tasks (1999, 2002). However rote learning is not as constructive on its own as integrating it within a larger goal of meaningful learning (Mayer, 2002). Teaching by transmission suggests an approach where the teacher has greater control of teaching and learning. Bernstein and proponents of his theories claim that strong framing, that is strong control over the teaching and learning environment, may in fact be more beneficial for working class students than other teaching and learning approaches (Bernstein, 2000; Bertram, 2008; Hoadley, 2006; Morais, 1996, 2002).

The transmission and student-centred approaches are two approaches to teaching and learning that dominate the literature. If teaching approach is viewed as a continuum, then transmission and student-centred teaching are viewed as sitting on extreme ends of the continuum. An elaboration of the student-centred view of learning follows.

3.3.2 The student-centred view of learning. The constructivist view of teaching and learning is often associated with a student-centred approach. Constructivism, as a philosophy of teaching and learning, has received international recognition for its use in mathematics education (Jaworski, 1994). It is widely recognized that constructivism has its origins in the cognitive theories expounded by Piaget (1967) and Vygotsky (1978). Other theorists in mathematics education, for example Coben (2003), contend that, epistemologically, constructivism views mathematics as a process rather than a product, asserting that knowledge of mathematics is gained by doing mathematics. The constructivist theory of teaching and learning contends that students learn through making sense and making connections with prior knowledge as opposed to absorbing mathematical knowledge that is presented to them (Benn, 1997). Wilson & Lowry (2000) extend this view when they contend that students' learning of mathematics is improved when it happens through meaningful social interactions with their communities. Cobb *et al.* (1991) explain that "from the constructivist perspective, mathematical learning is not a process of internalizing carefully packaged knowledge but is instead a matter of reorganizing activity, … [which includes] conceptual activity or thought" (p. 5). This statement seems to suggest that direct instruction does not encourage conceptual development. Be that as it may, Maher (2002) suggests that direct instruction (or teaching by transmission) is in fact a necessary precursor for conceptual development and therefore very much a part of the learning process.

Kirschner, Sweller and Clarke (2006) claim that constructivism is based on the premise that learners construct their own knowledge and that for students to learn constructively they require an environment that offers minimal guidance. A minimally guided learning environment suggests an environment in which students have more control over their learning and where there is flexibility in terms of the selection, sequencing and pacing of knowledge. Be that as it may, while the minimally guided approach resonates with what Bernstein refers to as weak framing, his theory suggests that weak framing is not regarded as an approach to teaching and learning that benefits working class students. The concept of minimal guidance suggests that the realization rules are not made clear thereby limiting the opportunity for the student to acquire the recognition and by extension the realization rules (Bernstein, 2000). The student-centred view therefore has implications for teaching and learning. Constructivist educators thus view the activities from the perspectives of both the teacher and the student. Learning environments and activities that provide opportunities for acquiring basic skills and which encourage conceptual development should be key features in the constructivist classroom (Koehler & Grouws, 1992; Wilson & Lowry, 2000). Having discussed two dominant approaches to teaching, theoretical perspectives on problem solving as an instructional goal are discussed below.

3.3.3 Problem solving as an instructional goal. This section of the review defines problem solving within the context of this research and presents a discussion on strategies used in the development of problem solving skills. While the literature provides several definitions for the term problem solving, others have written that it is difficult to generate a single definition of a mathematical problem (Mamona-Downs & Downs, 2005), not possible (Grugnetti & Jaquet, 2005) or outdated (Lesh, 2003; Lesh, Hamilton, & Kaput, 2006; Lesh, Zawojewski, & Carmona, 2003; Rosenstein, 2006). However, I decided that, for the purposes of this study, it was necessary to formulate a common understanding of the term against which to gauge the identification of authentic mathematical problem solving. Lesh & Zawojewski suggest that a mathematical problem is one that is authentic, reflects a problematic and requires “problem solvers ... to develop a more productive way of thinking about the given situation” (2007, p.31). Polya (1965), distinguishing between ‘know-how’ and information, claims that know-how is more important than information. He describes know-how as the ability to solve non-routine problems that require original, independent thinking and creativity. Drawing on the descriptions and definitions discussed, a common characteristic of a problem is that it must be ‘novel’ for problem solving to be involved, suggesting that it should be different from what has been solved before (Polya, 1962; Schoenfeld, 1992).

Lester and Kehle (2003) propose that mathematics problem solving must include reasoning and or higher order thinking, must be non-routine, is contextualised and is not based on the use of pre-learned algorithms. While that may be true, Resnick and Ford (1981) claim that drawing from algorithms for part of the process is acceptable, provided some part of the process is non-routine and the algorithm is not the only mathematical process executed. Francisco and Maher (2005) claim that problem solving involves some degree of reasoning which leads to meaningful learning:

> problem solving recognizes the power of ... construction of ... personal knowledge ... that emphasize minimal intervention in ... [a] mathematical activity and an invitation to students to explore patterns, ... reflect ..., explain and justify their reasoning ... as integral parts of the process of problem solving. (Franciso & Maher, 2005, p. 362)

Similar views are shared by authors who emphasise that conceptual understanding is an inherent component of the process of problem solving and characteristically requires several iterations to come up with a correct solution as it is not likely to be real problem solving if the solution is automatically apparent to the student (Dunker, 1945; Hiebert *et al.*, 1997; Krathwohl, 2002; Lester & Kehle, 2000; Lesh & Zawojewski, 2007). Using Bernstein's concept of framing, using several iterations to solve a problem, suggests that the problem solving process requires weak pacing and sequencing. Maher describes problem solving in terms of a 'given state' and a 'goal state' where students engage in a "series of mental operations that are directed toward some goal" (Maher, 2002, p.124). The view of problem solving from a given state to a goal state suggests that the process is strongly framed in terms of the evaluative criteria as there is a predetermined goal to be achieved. While a predetermined goal implies that the recognition rules are explicit, it does not necessarily imply that students will acquire the realisation rules necessary for success.

Having viewed what stalwarts in the area of mathematical problem solving have said, more recent studies have found that mathematical problem solving is used and accepted widely as a means of developing conceptual understanding in mathematics (Cai & Lester, 2005;

Mamona-Downs & Downs, 2005). Mathematics experts concur that problem solving should comprise more than one approach to solve the problem: the use of flexibility in thinking, understanding of concepts and the need to grapple with finding the solution. Having considered the various views on problem solving, drawing from the understandings discussed above the following working definition was derived and used in this study. Problems solving occurs when the problem:

- is novel;
- requires non-routine strategies and
- requires reasoning (more productive ways of thinking about the solution).

Having established the definition of problem solving used in this study, some suggestions of teaching and learning approaches that lead to the development of problem solving skills are described. Mayer (2002) suggests that training to develop problem solving skills should include translation training that is concerned with linguistics comprehension; schema training which is related to structural understanding; strategy training to provide instruction on how to solve problems and algorithmic automaticity.

Bloom and Broder (1950) conducted a study with two groups of students to determine whether instruction in problem solving enhanced the development of problem solving skills. The control group was given no instruction while the experimental group was exposed to the problem solving processes of successful students that they were asked to imitate. The experimental group who imitated the problem solving processes of the successful students performed better than those who did not indicating that instruction in problem solving enhances the development of problem solving skills. Similarly, Kirschner *et al.* (2006) assert that their review of empirical studies show that worked examples are more effective than using heuristics. A study by Sweller and Cooper (1985) shows that students learned more algebra using worked examples than solving equivalent problems on their own. It is evident from the literature that there are various contentions with respect to how teaching and learning mathematics should be approached. In attempting to understand what motivates academics' approaches to teaching and learning I looked at underlying factors such as teachers personal beliefs about mathematics and teaching mathematics for engineering students.

The section above was a discussion of teaching and learning mathematics from a science and engineering perspective and is considered relevant as the ME module is taught by mathematicians. It was established that teachers' approaches to teaching play a significant role in students learning. Furthermore, the discussion elaborates on justifications for the choice of approaches and resultant findings where they have been confirmed. Following this is a discussion of some current trends adopted in teaching and learning mathematics to engineering students.

3.4 Current Trends in Teaching Mathematics to Future Engineers

Engineering education has recently emerged as an area of research globally, with engineering educators and educationists looking to identify teaching and learning approaches with the aim of improving enrolment, attrition and graduation rates in engineering. Since this study is concerned with teaching and learning mathematics to first year engineering students, literature pertaining to the same has been consulted. This section provides a brief introduction to the nature of mathematics in engineering which is taken up further in Chapter five, highlights current trends in engineering education, more specifically in the mathematics education of future engineers that have seen a change in focus from traditional approaches to teaching and toward more student-centred approaches. Traditional approaches to teaching and learning are generally associated with a curriculum that is reflective of strong classification and framing while student-centred approaches in Bernstein's terms relate to weak classification and framing. Current literature in engineering education highlight the following teaching and learning approaches used in the mathematics education of engineering students: the emphasis on using real world examples to highlight the relevance of mathematics in engineering (weak inter discursive boundaries or weak boundaries between every day and academic knowledge), the integration of content (weak boundaries between subjects), attention to learning outcomes such as the skills required of engineers in practice (for example communication and teamwork skills) and the debate between the extent of mathematical knowledge necessary for engineering students and in engineering practice. The discussion that follows highlights some of the views expounded by proponents of the various approaches.

3.4.1 Nature of mathematics in engineering. In the context of engineering, Bickley (1964) described mathematics as a tool that is used to understand and control the world that we live in. Nearly three decades later, Barry and Steele (1993) use a similar analogy (toolkit) to refer to mathematics that engineers require for effective engineering practice. Sazhin (1998) claims that mathematics is a language that can be used to describe the laws of physics and chemistry suggesting that in order to understand an engineering problem one needs to be able to convert it into a mathematical equation based on its physical and chemical descriptions. In congruence, Blockley and Woodman claim "mathematics is a language of scientific communication" (2002, p. 6) and the ultimate form of logical rigour which engineers are required to engage in. According to them logical rigour, developed through theorem proving and Euclidian geometry, is necessary if creativity is to be unleashed. The nature of mathematics in engineering is discussed in greater detail in Chapter Five.

3.4.2 The extent of mathematics to be taught. Sazhin (1998) claims that while engineering students are more likely to think in terms of numbers than in terms of abstract mathematical concepts they require mathematics that will enable theoretical and physical understanding of the phenomena. Understanding an engineering problem is about changing it into a physical or chemical problem and representing it mathematically. In his article, *Teaching mathematics to engineering students*, Sazhin (1998) emphasises the need to find the right balance between the "practical applications of mathematical equations and in-depth understanding" (p. 145) to avoid "studying topology *ad infinitum*" (p. 147). The study of certain abstract mathematical concepts is relevant in situations where demonstrating the practical application of it is not possible. For example Sazhin explains that demonstrating the inside of an internal combustion engine is not possible as it cannot be touched, hence the theoretical explanation of the working of an internal combustion engine would have to suffice. In this case Sazhin acknowledges that at times it is necessary for content to be strongly classified. Furthermore, he claims that using practical examples to enhance the understanding and relevance of new and abstract mathematical concepts enables students to effectively move from surface to deep knowledge. While Sazhin (1998) acknowledges the need for teaching abstract mathematics, he also acknowledges the need for weak boundaries to facilitate understanding.

Felder *et al*. (2003) privilege a curriculum which incorporates a balance between the presentation of abstract and concrete information. They argue that knowledge which is not grounded in students' experiences (strong classification of content) is less likely to be retained in long term memory (Felder *et al.*, 2000). Be that as it may, Case (2011) argues that when knowledge is grounded in the context of the problem (weak classification of content) it is difficult for students to make generalizations from concrete information to higher levels of abstraction. Speaking in the context of South Africa, Case asserts that such an approach disadvantages already disadvantaged students who form the majority of the first year engineering cohort. Case's contention supports that of Bernstein who uses the concept of classification to explain that strong integration between vertical and horizontal discourse (academic and everyday knowledge) constitutes weak classification on an interdisciplinary level. Wheelahan (2008) also argues against contextualising learning, explaining that in such an approach abstract theoretical knowledge is displaced as a central feature of the curriculum. This potentially deprives students of access to theoretical understanding of the content and thus the opportunity to engage in conversations about society and where it is going (Bernstein, 2000). This, according to Bernstein, inhibits the achievement of democracy. Weak classification between discourses makes it difficult for working class students to acquire the recognition rules thereby reducing their chances of success (Bernstein, 2000).

The changing landscape in engineering and higher education, have been motivating factors behind the recommendations of the Australian Mathematics Science Institute (Broadbridge & Henderson, 2008). The changes include students' lack of competence in mathematics (under-preparedness), large classes and accommodating new, much-needed modules, for example, professional practice. The recommendations include reducing the amount of mathematics taught to engineering students and encouraging students who are mathematically strong to pursue a double degree with the aim of producing engineers who can contribute to the mathematical competence of engineers in the country. This suggests that not all engineers require a solid background in mathematics and that students who wish to take up more mathematics be provided with the opportunity to do so. This section discussed the mathematical knowledge that students require to function competently in engineering practice. Some authors contend that mathematics in all its' abstraction is necessary, others argue for a balance between abstract mathematics and its' application, while yet another perspective is that not all engineers require abstract understanding of mathematics. While the debate on the extent of mathematics that is necessary in an engineering curriculum is an ongoing one, the focus on the competencies required of engineers has also been a driver of change in the engineering curriculum. The following section addresses this.

3.4.3 Focus on competences required in engineering practice. Current thinking in higher education spurred a shift in teaching and learning from a traditional focus on what a graduate knows to an outcomes-based focus on what the engineering graduate can do (Case, 2010). In South Africa, proposals for curriculum change have been suggested in response to demands of external bodies including, the state, industry and ECSA, to enhance student participation, predominantly for the traditionally marginalized (Case, 2010). This is in accord with industry and ECSA requirements which demand that engineering graduates be 'work-place ready' upon graduation. However engineering students "are graduating with good knowledge of fundamental engineering science and computer literacy, but they don't know how to apply that in practice" (Mills & Treagust, 2003, p. 3). This quote suggests a lack of delivery on the part of the engineering curriculum and higher education with regard to the needs of industry. Such assumptions underlie the need for change in the curriculum.

One of the proponents of curriculum change, Walkington (2002), claims that the engineering curriculum must be responsive to and able to predict and thus be pre-emptive in responding to the actual and potential needs of stakeholders. The lack of skills evident in graduate engineers has been acknowledged by academics who suggest that the skills that students require call for different educational approaches that need a shift in paradigm from a focus on teaching to learning (Timmerman, 2004). This recommendation is supported by the European Society for Engineering Education (SEFI) Mathematics Working Group (MWG) (SEFI, 2013) who have committed to reviewing the curriculum document for the mathematical education of engineering students every decade to bring it in line with current curriculum practices. Since the first document, the focus of the curricula has transitioned from mathematics content to learning outcomes and most recently to a focus on competencies. The premise underlying this thinking is that understanding the relationship between the competencies that students should achieve from exposure to mathematics enables one to see the role that mathematics and mathematics education plays in achieving those very competencies (SEFI, 2011).

This point made above is entrenched by Alpers (2010) who conducted an ethnographic study in a German University to investigate the mathematics that mechanical engineers required. His findings show that that one of the major goals of the mathematics education of engineering students is to enable them to understand and apply mathematical concepts in further engineering modules. This requires lecturers to have an understanding of the relevance of mathematics in engineering practice, of other engineering modules and an understanding of the mathematical competencies that are required of engineers to be able to develop those in students. Alpers (2010) articulates these competencies as thinking, reasoning and modeling mathematically, posing and solving mathematics problems, handling mathematical symbols and formalism (Alpers, 2010). The focus on competencies required of practicing engineers has fueled the way the teaching and learning of engineering students is conceptualised and influenced the current change in focus from teaching to learning. This shift in emphasis from teaching to learning is discussed in the section that follows.

3.4.4 Approaches to teaching and learning engineering mathematics. The quote below from Seshaiyer (2011) captures two approaches commonly adopted to teaching mathematics to engineering students: “Here is the mathematics, go solve the problem”, rather than, “Here is the problem. Let us find the mathematics to solve it” (p. 1). The literature I have concentrated on interrogates current thinking in engineering and mathematics education globally to identify trends in teaching and learning mathematics to engineering students. The review shows that current curricula including teaching and learning approaches are designed in response to the changing higher education and engineering environment, the changing student profile and research in engineering education (Borrego & Bernhard, 2011). Research in engineering education highlights the critical role of mathematics in engineering and marks it as an important area of investigation in higher education. This review reports on the effectiveness of the approaches implemented and reveals two dominant schools of thought that drive the mathematics education of engineering students: one which professes that mathematics is application based and includes relevant problems in engineering (weak classification) and the other which argues the value of a holistic approach to mathematics, that is, theoretical and abstract mathematics (strong classification) supplemented with application in engineering contexts (weak classification).

International literature on engineering education shows that instructional practice, in response to the call for change, has evolved in many ways in order to enhance student learning. Teaching approaches have moved from a focus on traditional, transmission approaches to student-centred approaches some of which include Problem-Based Learning (PBL), Project-based Learning and Computer-based Methods (MathLab and MathCAD). While these changes are documented in the literature, more recent reports also highlight the need to enhance learning so that engineering graduates are enabled to meet the needs of the 21^{st} century (Colby, & Sullivan, 2009; Jamieson & Lohmann, 2009). Lakoma (2002) suggests that changes in environment require people to not just be able to continue with their normal routine behaviour, even in the workplace, but also to adapt to new environments. Education should thus prepare students for knowledge that can be used on an operational level with key competencies that form the basis for further learning. In essence Lakoma claims that education must prepare students to be creative and use their cognitive abilities rather than develop skills that can only be applied in specific situations. Advancements in technology have rendered mathematical competencies indispensable to all. Litzinger *et al*. (2011) contend that to prepare students with the expertise that they require, to adapt easily to the challenge of novel (non-routine) problems that they will encounter as practising engineers, they need to develop the skills and knowledge that will enable them to do so. They assert that undergraduate engineering education forms the basis for the development of expertise that is needed in engineering practice. The literature discussed below identifies some teaching approaches that have been identified as leading to the development of the desired skills and knowledge.

3.4.5 Focus from teaching to learning. In her paper, *Tracking the Processes of Change in US Undergraduate Education in Science, Mathematics, Engineering, and Technology (STEM),* Seymour (2000) reports on a meta-analysis of 21 institutions in the US over a period of 10 years. She gives an account of the changes made in approaches to teaching and learning in response to the high attrition rates and decreasing enrolment rates in science, mathematics and engineering subjects, the changing higher education landscape and the lack of mathematical competencies demonstrated by students. The reconceptualised curriculum focused on content, pedagogy and assessment and promoted the scholarship of teaching and learning, encouraged the use of active learning strategies and conducted professional development workshops with staff. Furthermore, the new curriculum addressed the need to reformulate assessments to ensure that they aligned constructively with learning goals and the use of feedback to enhance teaching and learning. Curriculum content was reviewed through discussion and dialogue amongst academic staff. While this meta-analysis highlights the changes in teaching and learning approaches in 21 institutions in the UK and the reasons that motivated the changes, the impact of these changes have yet to be documented.

Be that as it may, Muller (1998) asserts that some of the more ‘progressive’ curricula that claim to bring about equality and social justice can in fact have just the opposite effect. For example, the motivation to enhance student learning has seen shifts towards Problem-based Learning (PBL) and Project-based Learning. These require a weakening of classification and framing more particularly in PBL. However, Case (2011) suggests that the weakening of classification and framing with the intention of enhancing learning could have consequences for student learning that contradict the intentions of the teaching and learning approach. Such approaches to teaching and learning require an academic identity that working class students may not have acquired. Bernstein (2000) contends that the curriculum is the vehicle through which the interests of the dominant groups in society are perpetuated through the education system. Pre-1994, the state used the curriculum to perpetuate the dominant ideology of apartheid. Since democracy is achieved through greater autonomy and self-control, it stands to reason that in the new democracy education reform would have to target curriculum change (Muller, 1998). The work of Bernstein provides insight into aspects of the curriculum that influence the success of traditionally disadvantaged students (Hoadley, 2006). This suggests that engineering curricula might need to be strongly classified to ensure the distinction of specialised knowledge (Muller, 1998).

This section has shown that current thinking about teaching and learning has been a strong motivator for re-conceptualising engineering education with some institutions embracing curriculum change by placing greater emphasis and attention on teaching and learning (Clegg, 2009; Timmerman, 2004). As mentioned in the introductory paragraph, another approach that has been widely used in the teaching and learning of mathematics to engineering students is the use of problems that are relevant in an engineering context. The next section discusses and argues the use of this approach.

3.4.6 Relevance to engineering (every day and academic knowledge). Whitehead asserts that education enables the student to acquire the art of applying knowledge and not memorization (1929). He advises that the mind is responsive to stimulus and that the golden rule of education is to fuel that stimulus by adopting innovative methods that stimulate the mind. Lack of innovation and support of strategies that encourage memorization stifle the mind and ultimately, therefore, the essence of education (Whitehead, 1929). Bordogna, Fromm and Ernest claim that engineers are people who are,

> responsible for applying new knowledge to create what has never been ... thus the intellectual mission of educators must include the cultivation of ... students' ability to bridge the boundaries between disciplines and make the connections that produce deeper insights. (Bordogna, Fromm and Ernst, 1993, p. 4)

Their quote suggests that the mathematics education of engineering students should include application of mathematical concepts in engineering contexts. It also suggests the inclusion of abstract mathematics to enable students to 'produce deeper insights' and to engage in creating new knowledge. Their view advocates a change in the traditional paradigm of teaching the different engineering disciplines in isolation of each other to teaching in a way that 'bridge[s] the boundaries between disciplines thereby reflecting engineering education as an integrative process. Arguably, Bordogna *et al*. (1993) claim that generally engineering education privileges the study of disciplines in isolation of each other and produces students who lack the ability to see and integrate the connections between disciplines. They maintain that currently engineering education reveals a reductionist approach.

Similarly, Felder, Woods, Stice and Rugarcia (2000) contend that for the engineering degree to be completed in the given time constraints, better teaching methods need to be employed than the ‘trust me’ approach which they elaborate on as the “trust me-what I’m teaching you may seem pointless now but in another year or perhaps in four years you’ll see why you needed it” approach (2000, p. 4). They claim that traditional lecture-style teaching approaches are still currently rife in engineering classrooms. Felder *et al*. conducted a meta-analysis of studies that focused on instructional practices which met the following criteria: they are relevant in engineering, are underpinned by current theories of learning, they require little practice for lecturers to be comfortable using and have been found to be successful in various contexts with independent researchers. Their findings support their rationalisation that students learn best when they see the relevance of what they learn. Felder *et al*. (2000) suggest that to achieve these criteria content be taught inductively using application in engineering contexts.

The discussion above was an overview of theory and research that appear to be particularly relevant to the development of methods for teaching mathematics to engineering students. To further highlight the shift in focus in teaching and learning approaches, studies on current trends in engineering education are presented next.

3.5 Studies on current trends in engineering education

The recommendations of the Engineering Council (UK), in response to widening of access to higher education and the mathematical under-preparedness of first year students were to conduct a diagnostic test for all students entering mathematics based courses and to develop and implement effective support (strategies) for students whose performance in the tests were low. Williamson, Hirst, Bishop and Croft (2003) conducted a meta-analysis of the strategies that were developed and the effectiveness of their implementation across the engineering and higher education institutions in the UK. Williamson *et al*. point to the need for engineers to be able to determine economical solutions to technical problems making the empirical and abstract understanding of mathematics a key concern. They found in their meta-analysis that strategies which yielded positive results and which constituted good practice were based on a holistic approach to teaching mathematics to future engineers. These include the use of: technology-based software such as Mathcad as it relates mathematics to real engineering problems and the use of Mathlab as it enabled students to 'see' the mathematical ideas more clearly; teaching mathematics within an engineering context and finding the balance between providing an in-depth understanding of mathematics and the inclusion of practical applications of mathematical equations (2003).

A survey conducted on lecturers involved in engineering education in higher education in the UK yielded their perceptions that the inadequate mathematical background of students compromised the quality of their engineering degree (IMA, 1995). While parallels can be drawn between some of the challenges faced by engineering faculties in the UK and those at the SAHEI, for example, the inadequate mathematical background and diverse socio-economic and educational backgrounds of students, they differ in that while HEIs in the UK accept students with low secondary school mathematics performance into engineering, the SAHEI selects students on the basis of merit with respect to their Mathematics, Science and English marks.

Similar results were yielded by a study conducted by Klingbeil, Mercer, Rattan, Raymer and Reynolds (2004) at the Wright State University (WSU). They note the failure of many engineering students to successfully pass the freshman calculus course. A traditional approach was being used in the first year calculus course that was aimed at providing the mathematical theory required for engineering modules. The application to engineering contexts was left to subsequent engineering modules. The dissatisfaction with this approach compounded by a 42% completion rate and an attrition rate of 58% (due to students changing their course of study or dropping out of university) culminated in an attempt to increase retention rates, student enthusiasm and success in engineering. The change included the integration of engineering application into the freshman calculus module with the acknowledgement that a more drastic approach to the engineering curriculum was needed. The first year module was changed to include only salient mathematics topics which were relevant to engineering courses and were reinforced through hands-on, laboratory assignments. The seventy-six students enrolled in the module were divided into two groups. The performance of students was based on their final grades and showed a positive outcome with 80% of students passing with at least a ‘C’ grade. Finer analysis of the data included a comparison of students with a high school mathematics background against those who did not and concluded that high school background did benefit students since 80% of the former group achieved ‘A’ and ‘B’ symbols while 48% of the latter achieved the same. This data does not include students who dropped out or failed. In addition, students’ perceptions of new mathematics course were positive and indicated that it had improved their chance of success and by extension retention (Klingbeil, Mercer, Rattan, Raymer & Reynolds, 2005).

Recognizing that mathematics is central to advances in fields such as engineering and information technology (Henderson & Broadbridge, 2007), the Australian Mathematics Sciences Institute (AMSI) in Melbourne called for engineering students to receive a solid grounding in mathematics. This was made more challenging by the rapidly advancing technology, a diverse student body, students inadequately prepared for higher education, widened access to higher education, international students and working students. To develop strategies to address the challenges associated with the mathematical education of engineering students, a national review of the teaching and learning strategies used in engineering education in Australia was conducted. An advisory committee comprising fifteen representatives from Australian universities, Defense Science, Engineers Australia, Australian Council of Engineering Deans and Technology Organisation initially conducted a literature search to identify best practice. They found the Helping Engineers to Learn Mathematics (HELM) project in the United Kingdom to be an example of such practice. Using a case study approach the Advisory Committee developed a questionnaire to collect qualitative data from the mathematical and engineering staff of twenty-seven Australian institutions to appraise the mathematics being taught to them and to identify interesting practices that were being used. The findings from their study revealed that the most effective mathematics modules in engineering comprised of curricula which focused on the relevance of mathematics in engineering, assisted students to develop conceptual understanding, addressed student diversity and had easily accessible student support.

In response to a study conducted by the Engineering Council UK on the nature and degree of difficulties faced by engineering students, the Institute of Mathematics and its Application (IMA, 1995) recommended that mathematics topics be taught within an engineering context, suggesting in Bernstein's terms, a weak classification between every day and academic knowledge. Kent & Noss (2000) comment that the traditional notion of mathematics as a service subject implies that mathematics needs to be taught to engineering students as a pure science with engineering modules taking responsibility for how it is to be applied at a later stage. They examine the notion of a 'model' in mathematics with the purpose of identifying how it is mathematical as compared to how it is part of engineering and how students and experts link these in their minds. Ward (2003) argues that teaching what he calls the 'language' of mathematics enhances accessibility and use as opposed to a focus on teaching techniques in mathematics. The lack of using contextualised problems, while still valuable to the engineering student, potentially disconnects the mathematics learned from other engineering modules (Craig, 2010).

The review of the literature concentrated on interrogating current thinking in engineering and mathematics education globally to identify trends in teaching and learning. The need for engineering and mathematics educators to acknowledge the changing landscape of engineering and higher education was highlighted. The review drew on research conducted internationally and presented a global picture of current teaching and learning approaches to mathematics for engineers. This review highlighted the core role that mathematics plays in the study of engineering and in engineering practice. Two dominant views emerged, one that values the theoretical underpinning of mathematics and the other that embraces the value of the same but argues that it is not necessary for engineers to have such understandings. Both approaches to teaching and learning mathematics in engineering education include application-based teaching using problems in relevant engineering contexts and teaching the theoretical basis of mathematics with applications in relevant engineering contexts.

3.6 Some Current Approaches in Engineering Education

Of the approaches that emerged from the literature on engineering education problem-based learning (PBL), Project-based Learning and Computer-based Methods (CBM) are three approaches that are widely used. This section focuses on the following two instructional strategies: Problem-based learning (PBL) and Computer-based methods (CBM). PBL has been widely accepted as an appropriate teaching and learning strategy in many engineering contexts (Barrows & Tamblyn, 1980; Kirschner, Sweller & Clark, 2006; Kolmos, 2006; Veldman, De Wet, Mokhele & Bouwer, 2008). In Denmark, Aalborg University has at least seventy-five percent of its engineering curricula approached from a PBL perspective.

3.6.1. Problem-based learning (PBL). Problem-based learning as described by Barrow and Tamblyn is "the learning that results from the process of working toward the understanding or resolution of a problem where the problem is encountered first in the learning process" giving students the opportunity to solve problems across disciplines (1980, p. 18). This enables them to develop problem solving skills in the relevant area. PBL is also known as a 'minimally guided approach' (Kirschner, Sweller and Clark, 2006) that encourages an effective and efficient teaching and learning environment for teaching engineering students (Veldman, De Wet, Mokhele & Bouwer, 2008). It rests on the philosophy that authentic learning contexts encourage students to identify and learn knowledge that is required to appropriately tackle real-world problems (Barrows & Tamblyn, 1980). The role of the teacher in a PBL environment is to facilitate student's knowledge construction using collaborative techniques (Kolmos, 2006) since having 'sound knowledge' is no indication of whether this translates into good practice. The student develops an integrated body of knowledge related to the discipline and problem solving skills. Students are able to identify key aspects of a problem, synthesise information and use deductive skills to solve the problem at hand. Some of the advantages associated with PBL is that it promotes lifelong learning, students become self-regulated learners and learning is more effective and rewarding for students (Barrows & Tamblyn, 1980).

Be that as it may, Case (2011), while acknowledging the merits of PBL, points out that PBL is not without its criticisms. The success of PBL depends on students being sufficiently responsible and disciplined to tackle a problem in a way that develops their problem solving skills and leads them to self-directed learning. Case asserts that PBL does not necessarily enable students to develop abstract understanding. She explains that PBL rather than enable students to meet the outcomes professed, may impede the development of those very outcomes. This is attributed to minimal guidance and explanation of concepts which using Bernstein's terminology reflects a weak classification of teacher-student relations and weak framing over evaluative criteria. Moreover, in PBL the knowledge of concepts is said to be well-grounded in the context of the problem making generalization from the problem to abstract understanding difficult. Since tasks are measured against the achievement of the expected outcomes this results in students underachieving. Case argues that exposing students to 'authentic' problems can be disadvantageous to students who do not match the 'ideal' student envisaged, the 'ideal' student being normatively middle class with exposure to good schooling. The reason given is the working class student's lack of tacit knowledge deemed necessary for successful participation in PBL (Case, 2011). However, once the basic concepts are in place understanding other problems will be quicker provided there is alignment between teaching and assessment that support PBL (Barrows & Tamblyn, 1980).

Mills and Treagust (2003) assert that there are obstacles to the implementation of PBL in totality across an entire engineering curriculum and relate it to the nature of engineering knowledge as compared to the nature of knowledge in disciplines such as medicine. The knowledge structure of mathematical sciences is hierarchical which means that the sequence in which topics are learned is important. Topics that are missed or not taught in sequence will make the learning of subsequent concepts more challenging as it will be difficult for students to 'catch up' on missed topics. In other words, the knowledge structure in mathematics requires strong framing over sequencing while PBL as an approach exhibits weak framing over sequencing since concepts are learned in the order in which they are encountered or needed to solve the problem. These concerns are shared by Perrenet, Bouhuijs and Smits (2000) who claim that PBL has limitations in engineering education and is therefore a less suitable strategy. On the other hand a PBL approach may be more appropriate in medical education due to the knowledge structure of the medical sciences which has been described as having an 'encyclopedic structure' (Perrenet *et* *al.*, 2000). Hence in medical education, the order in which concepts are learned is not important as missed topics can always be learned later without severe repercussions.

The following studies focus on institutions in Australia which sought to include professional topics in their engineering curriculum that would encourage the development of team work, communication and report writing skills. This was a response to industry pressure for engineering graduates to demonstrate such skills. Jayasuriya and Evans (2007) report on a study conducted at the Victoria University on the effectiveness of PBL, used in all engineering subjects, which yielded positive outcomes. At the Victoria University, first year engineering students are taught mathematics in small groups of between twenty to thirty engineering students. The curriculum includes three hours of interactive sessions and an hour of working on the in-context engineering problem (group project) which draws on the mathematics addressed in the interactive sessions. The feedback from students and staff show that the approach is effective in reinforcing mathematical concepts engaged with the in-context engineering problems. Student comments were supportive of a PBL approach as they indicated students' appreciation for the opportunity it provided for them to develop team work skills, peer assessment and the positive social experience that team work provided, especially for them as first year engineering students (Jayasuriya & Evans, 2007).

Barry and Webb (2006) describe an interdisciplinary PBL approach which they used at the University of South Wales in Canberra. They collaborated between engineers, computer scientists and mathematicians to develop six real-world engineering problems. Each problem is based on a specific numerical method and is allocated as an assignment every fortnight. There are two lectures supplemented with four hours of computer lab work during that period. Students are presented with a problem, are required to represent it mathematically, design a code in MATLAB to analyse it and interpret and represent the answer as an engineering problem. The six assignments constitute 50% of students' final mark with the balance of the marks allocated to a closed book examination comprising little problems which assess the knowledge gained from the assignments. The reported benefits of this approach include the development of students' team work skills and the skills to solve engineering problems, the ability to write well-structured assignments and became comfortable using computer software (Barry & Webb, 2006). A similar teaching and learning approach was adopted at the University of South Australia with comparable outcomes. Colgan (2000) reported that students' report writing, team work and self-study skills were enhanced. The approach included three hours of traditional lectures, an hour of tutorial and an hour of MATLAB during computer laboratory sessions. Students had to complete two group projects, one being a real-world engineering problem and the other a report based on a topic not covered in lectures.

Be that as it may, Britton, New, Sharma and Yardley (2005) investigated the ability of 47 first year science students to transfer their mathematical skills to different contexts. Three scientists and a mathematician developed a set of questions to assess the performance of students on in-context and out-of-context problems. Students' performance on each were analysed and interpreted to quantify the extent of their ability to transfer mathematical skills from in-context problems to other contexts. While the findings show a correlation for high-performing students' on in-context and out-of-context problems, the findings were not the same for students whose performance on in-context problems were average. Students whose performance on in-context performance were average, did not perform well in the out-of--context problems suggesting that they were limited in their ability to transfer mathematical knowledge to other mathematical contexts (Britton *et al*., (2005). The findings for average performing students are in keeping with Case (2011) and Mills and Treagust (2003) who argue that when mathematics is ingrained in the context of the problem it is difficult for students to develop abstract understanding of the mathematical concepts.

3.6.2 Computer-based methods (CBM). CBM can be viewed in two ways: teaching through CBM to enhance learning and using computer-based software to perform computations. It is acknowledged that in recognizing the need for engineers to be proficient in computer programming and by extension knowledgeable in discrete mathematics, the value of using computers in engineering education as a computer-based method has become a valuable approach to teaching mathematics to engineering students (Barry & Demlova, 2008; Barry & Steele, 1992). The presentation of mathematical material may be enhanced by the use of computer software specifically designed for that purpose, thereby reducing the need for high-level manipulative skill. This would enable the emphasis in mathematics to be on conceptual understanding as opposed to manipulative expertise (Barry & Steele, 1993). Furthermore Barry and Steele suggest that advances in technology are likely to result in changes to the core curriculum every decade as engineers will require higher intellectual skills associated with mathematical modeling and representation. They explain that discrete, algebraic or numerical outputs produced by the computer require engineers to be proficient in appraising the value of the mathematical information embedded in the output. Effectively, engineers will be called upon to understand the scope and limitations of powerful computers and to make sense of highly sophisticated outputs. Barry and Steele acknowledge that mathematical modeling is most widely known as the "most constricted bottleneck in the entire mathematical learning" (Barry & Steele, 1993, P. 225) and assert that the approaches declared most appropriate in teaching it are highly debatable.

According to Barry and Steele, the engineer does not require the extensive mathematical rigour required of mathematical experts, but sufficient mathematical knowledge to enable him/her to: (a) interpret and solve straightforward mathematical and statistical problems; (b) to communicate the outcome of analytical and statistical appraisals verbally and in written format; (c) to interpret computer solutions to problems and to comprehend basic mathematical models of problems in an engineering context. They suggest that mathematics for engineers is best taught by mathematicians as this affords engineers the opportunity to be exposed to "expertise, innovation and development" (Barry & Steele, 1993, p. 227) exhibited by specialists in the field. While they acknowledge the important role that traditional lectures and tutorials play in the mathematics class, they foreground the increasingly important role that the computer plays in teaching and learning thereby highlighting the need for an approach that uses a variety of teaching and learning strategies.

The Mexico State University's (MSU) concern with enhancing students learning was based on the premise that the exclusive use of traditional lecturing created a passive learning environment and that an active learning environment enhances students learning (Nirmalakhandan, Reckett, McShannon & Barret, 2007). To encourage active learning MSU adopted a combination of methods in a Hydraulics Engineering course. The researchers created twelve exercises which required students to work in groups of two or three to apply the theoretical concepts learned and to use the models (mathematical and physical) to analyse and simulate hydraulic phenomena. The study was conducted with 131 students at the MSU to determine the effectiveness of the integrated, active learning approach which was a combination of physical, mathematical and computer simulation models. The duration of the study was five semesters in a module using qualitative and quantitative methods of data collection and analysis. Surveys conducted at the end of the class and student evaluations at the end-of-semester were used to elicit student perceptions of the approaches. The findings show that the integrated approach was appreciated by students. In addition 90% of students were in strong agreement that the integrated approach enhanced their learning. Quantitative data supports the finding that student learning and achievement is enhanced. An analysis of the final grades show an increase from 70% to 86% in the number of students achieving in the range 'A', 'B' and 'C'. Similar findings were evident in a study conducted by Springer, Stanne and Donovan (1999) who administered eighty-five cognitive tests and pre and post-test implementation questionnaires to assess the effectiveness of the teaching approach adopted. The approach comprised of a combination of real examples and computer simulations in a PBL environment. The questionnaire data revealed a positive increase in fourteen of the seventeen items while the cognitive test showed a positive increase in all dimensions tested.

Current research in engineering education shows a shift in focus from teaching to learning which have been influenced by changes in the engineering and higher education landscape. Concerns of low enrolment and graduation rates, high attrition rates, widened access to higher education, a diverse student profile, under-preparedness for higher education particularly for the study of mathematics in higher education and increased demands of the workplace have created a complex higher education landscape. Traditional teaching is characterised by strong teacher control which indicates strong framing over pedagogy (Bernstein, 2000). According to Bernstein, strong framing over pedagogy is a more appropriate approach for disadvantaged students. Be that as it may the focus on learning reflects a move towards stronger student control over the learning environment signifying weak framing over pedagogy which according to Bernstein this is not the most appropriate approach for disadvantaged students.

The literature highlights the ongoing debate over how mathematics should be taught, with some authors arguing that integration of content across mathematics topics, between subjects and between every day and academic knowledge, is beneficial to engineering students as it fore grounds the relevance of mathematics in engineering. This approach resonates with Bernstein's concept of weak classification on intradisciplinary, interdisciplinary and interdiscursive levels. Bernstein argues that weak classification is detrimental to working class students as the weak insulation of boundaries does not make the mathematical content distinct. He contends that approaches that privilege strong classification (strong boundaries between content) are more appropriate for disadvantaged students (2000). In addition the literature on current trends brought to light the debate over what mathematics is necessary for engineers. That is, whether it is necessary for the engineer to study mathematics in all its abstraction (with the theoretical underpinnings) or to develop the procedural and computational skills that some authors felt was required in engineering practice.

Students' concepts of learning are related to the approach they adopt to learning. If they perceive learning in that subject as an accumulation of knowledge, they are more likely to memorise, rehearse and adopt a surface approach to learning. Those who perceive learning a topic as understanding and the abstraction of meaning are more likely to engage in a deep approach to learning. It is thus important that students have a complete concept of mathematics as a logical, complex system which can be used to solve problems. This means that university teachers need to understand how students perceive both the learning environment and the subject (Prosser & Trigwell, 1999). In the light of this, a discussion of theories of teaching and learning follows.

3.7 Student Approaches to Learning

The discussion in the previous section presented different views of the influence of teaching on student learning. This section discusses various approaches that students adopt to learning and attempts to provide some motivations for why they learn the way they do.

Ramsden contends that the “university teaching context might have unintended consequences for learning … they might discourage students from coming to grips with the fundamentals of their subject and encourage them to use tricks and strategies to pass examinations” (Ramsden, 1984, p.145). He asserts that students act in response to the situation that they perceive and often their actions are in contrast to what is actually specified by the teachers. The student might reduce actual high level objectives to a series of rules that facilitate them ‘passing’ the module. These findings are supported by Marton and Säljö (1976) who note that students’ approaches to learning are in response to the task on hand and are therefore not a static characteristic. Research shows that student approaches to learning can be distinguished into two dominant approaches to learning. These two approaches which arise from the literature are deep and surface approaches to learning (Marton & Säljö, 1976; Ramsden, 1992). Simplistically, these constructs refer to learning as conceptual understanding and learning as the accumulation and mastery of skills, variations of which have been discussed widely by various authors using different terminology (Kilpatrick & Swafford, 2001; Marton & Säljö, 1976; Mayer, 1992; Skemp, 1977, 1986). A third, yet related approach is identified as the strategic approach to learning which has been further qualified as strategic deep and strategic procedural approaches to learning (Case & Marshall, 2009). Deep, surface and strategic approaches to learning are discussed in this section together with approaches described by well-known authors in the field of mathematics education.

3.7.1 Surface approaches to learning. The surface approach to learning is characterised by an orientation to memorization and reproduction of knowledge with minimal attempt to integrate that knowledge (Marton & Säljö, 1976). Specific activities that students are given and expectations that teachers have of them tend to encourage surface approaches rather than deep approaches to learning. This approach to learning encourages memorisation of content and following of routine procedures without understanding the role of the content in the wider context (Skemp, 2006; Felder & Brent, 2005) thus reducing it to a collection of unrelated facts (Biggs, 1992). There is a lack of critical questioning and a passive acceptance of what is presented in textbooks and lectures which prioritise information that the lecturer deems important (Felder & Brent, 2005). Surface learning as an approach limits students from developing the type of understanding and engaging in the quality of learning required of university students (Prosser & Trigwell, 1999). Ramsden (1992) shows that student approaches to learning are relative as they tend to adopt approaches to learning in accordance with what they perceive the demands of that learning environment to be. Drawing on the examples provided by Prosser and Trigwell (1999) if students perceive assessment in a subject as requiring memorization and recall, if combined with a high workload they are likely to adopt a surface approach to learning in that subject. Wierstra *et al*. (2003) found that surface learning approaches result from the view of the teacher as authority and teaching as ‘giving’ knowledge to students. In other words, the view of teaching compares with Bernstein’s notion of pedagogic practice that exhibits strong framing. Surface approaches to learning are common in situations that demonstrate high workloads (Entwistle & Ramsden, 1983; Ramsden, 1991), a laden timetable, high volume of work and a threatening assessment system (Lizzio, Wilson & Simons, 2002; Biggs, 1992). Assessments are done for the sake of doing them with students not recognizing the relevance or value of them (Rust, 2002). Surface approaches to learning were shown to have better outcomes (higher student achievement) than deep approaches in situations where assessment measured the memorization, procedural knowledge and mastery of factual information (Lizzio *et al.*, 2002). From my own experience and in conversation with colleagues, there is anecdotal evidence that surface learning is a stepping stone to the development of conceptual understanding and that it becomes problematic when there is no development from the surface approach to a deep approach to learning. That is, the learning remains on the surface level.

3.7.2. Deep approaches to learning. Lakoma (2002) claims that advances in technology require people to have a strong mathematical background. In particular students need to be able to understand real phenomena and to do so they must be able to describe the phenomena and to distinguish their essential features (mathematical modelling). Students will then be able to hypothesise and make predictions, generate conclusions, and provide mathematical explanations for the phenomena. It is therefore critical that students are enabled to develop a deep rather than instrumental understanding of mathematical concepts (Lakoma, 2002). Students who adopt a deep approach to learning aim to understand and engage in making sense and meaning of the content. Prosser and Trigwell (1999) claim that students who adopt a deep approach to learning generally exhibit the following attributes: they relate the strategies they adopt to their own experiences, look for underlying patterns or principles and they "focus on the meaning in the argument" (p.3). However a deep approach is not necessarily characteristic of a student as students may adopt different approaches in different subjects depending on what the student perceives as the learning outcome. A high quality learning outcome can be described as ways of understanding that enable students to see relations between concepts and to apply that understanding to new and abstract situations. This is in contrast to ways of learning which limit students opportunities to develop in those ways (Prosser & Trigwell, 1999). The quality of the learning approach that the student adopts correlates strongly with the quality of student's learning outcome (Marton & saljo, 1997). Litzinger, Latucca, Hadgraft and Newstetter (2011) highlight the importance of deep learning claiming that expertise is underpinned by understanding. They assert that experts exhibit great quantities of knowledge but more importantly, their knowledge is underpinned by a deep understanding of the domain which is structured around key concepts of the domain.

When knowledge is new to students their organization of the basic concepts is superficial. This organization of knowledge is deepened when they attempt to find the connections between the ideas and concepts of that content (Biggs, 1992; Felder & Brent, 2005) and when they critically analyse the content for underlying logic, reason and justification. Deep understanding of knowledge is achieved through 'deep approaches to learning' (Litzinger *et al*., 1999). Deep approaches and motivation emerge from the literature as fundamental to the development of expertise. This approach is central to developing students' ability to "access and transfer knowledge to new and novel situations", while the role of motivation is seen as fundamental in enhancing the level of performance shown by students in educational settings (Litzinger *et al*., 2011, p. 124). In addition, the learning processes that lead to the development of expertise are significant as they form the basis for engineering education on which expertise in engineering practice is developed. Bransford, Brown and Cocking (1999) note that experts demonstrate deep understanding of knowledge, are able to see meaningful connections between concepts that novices do not, are able to retrieve knowledge with little effort and while they are knowledgeable about their disciplines, do not necessarily make good teachers. Findings from the literature on engineering education that focus on instructional approaches associated with promoting both motivation and deep approaches to learning are presented in this discussion.

3.7.3 Strategic approach-to learning. The strategic approach considers students to be tactical about the approach that they adopt in that they will assess the level of effort that is required and determine whether a surface or deep approach is most appropriate. Students are also savvy about time management and well organised. This approach is described by Felder and Brent (2005) as an approach that is achievement orientated. Students using this approach will do what is most beneficial to achieving their goals as they grasp what is required to pass the module with regard to assessment and examinations.

3.7.4 Rote learning. Learning is about the acquisition of knowledge and thus has implications for how information is transmitted (instructional practice) in lectures and in assessments (Mayer, 2001). Two educational goals, says Mayer (2002), are that learning should enable students to remember (retention) information and to make sense of it and to apply it (transfer) to novel problems. Rote learning occurs when students memorise facts and are able to recall key facts but are not able to apply or transfer this information to novel situations (Skemp, 1977, 1986). Bransford *et al*. (1999) claim that rote learning leads to poorly organized knowledge that does not facilitate the transfer of knowledge to novel situations. The concept of rote learning is incorporated in what Skemp (1977, 1986) terms instrumental learning.

3.7.5 Meaningful learning. Meaningful learning encompasses retention of knowledge as well as the integration of knowledge in solving novel or complex problems. It leads to the acquisition of knowledge and the development of cognitive processes that are necessary for problem solving. Problem solving involves first representing the problem and second, designing and implementing a plan for solving the problem (Mayer, 1992). This has implications for teaching since problem solving requires students to engage in meaningful learning which can be achieved through instructional practice (Mayer, 2002). This aligns with Skemp's (1977, 1986) concept of relational understanding. However, teachers and students need to have a common understanding of the expectations of the teaching and learning process for it to be successful (Fox, 1983).

A mismatch between teachers' and students' expectations of the teaching and learning process can lead to frustration and unsuccessful experiences for students. One type of mismatch occurs when teachers migrate to more progressive or student-centred approaches to teaching while students are inclined to traditional approaches. This situation can arise when students view learning as a transfer of knowledge and expect a well-structured work schedule and notes that facilitate learning and recall of information in assessments but is presented with opportunities for experiential learning and creative thought. In a different scenario, a mismatch can arise in a teacher-centred class when there is a high volume of work taught in short time frames giving students little opportunity to engage with the content and develop conceptual understanding (Fox, 1983). This section provided some insight into student approaches to learning. From the literature it is clear that understanding students' approaches to learning and the rationale for the approaches is a precursor to the teaching strategy that is adopted. Thus a summary of literature from national and international sources regarding teaching and learning mathematics in a Science and Engineering context is presented next and reveals the approaches that institutions across the world have adopted in engineering education.

Students' concepts of learning are related to the approach they adopt to learning. If they perceive learning in that subject as an accumulation of knowledge, they are more likely to memorise, rehearse and adopt a surface approach to learning. Those who perceive learning a topic as understanding and the abstraction of meaning are more likely to engage in a deep approach to learning. It is thus important that students have a complete concept of mathematics as a logical, complex system which can be used to solve problems. This means that university teachers need to understand how students perceive both the learning environment and the subject (Prosser & Trigwell, 1999).

While student approaches to teaching and learning are one aspect of the teaching and learning environment, assessment forms another important aspect of the same. Bernstein (2000) contends that evaluation condenses the pedagogic device, thus making assessment a culmination of teaching and learning. The next section presents the views of several authors who have written in the field of assessment.

3.8 The Role of Assessment in Teaching and Learning

Despite the fact that different modalities of practice may privilege some forms of assessments over others, tests remain the privileged means of assessment for the teaching and learning process (Morais, 1996). Brown (1997, p. 7) asserts that assessment defines "what students regard as important, how they spend their time and how they come to see themselves as students and then as graduates" and suggests that to facilitate a change in students' learning methods of assessment be changed. Given that, I believe that any dialogue concerning assessment can be considered incomplete if it does not include a discussion of those who do the assessment, what is being assessed, why and how it is being assessed. The relationship between those who assess and those who are to be assessed must be clear: What informs how academics assess and how students are prepared for assessment? Rust (2002) hints that while in many institutions there have been changes in paradigm from a focus on teaching to learning, which has resulted in student achievement being stated in terms of learning outcomes; assessment often fails to address these outcomes. He elaborates stating that while the module may be written in terms of learning outcomes, the assessments have remained the same, making the relation between assessments and learning outcomes, vague. Gibbs (1992) acknowledges that while the directive from the lecturer might be encouraging students to be innovative, students might understand that what is actually needed is memorisation.

Seymour (2000) acknowledges that the shift in concern from the decline in mathematics and science skills to competencies that are necessary for engineering lead to the change in focus to curriculum, pedagogy and assessment that enhance teaching and learning. The implications of this change in paradigm is that student understanding, reasoning and application are foremost, calling for alignment between learning outcomes and assessment. Assessments become a conduit through which students become actively involved in their own learning and provide feedback to educators on the effectiveness of the strategies used. This requires a change in the design of assessments from a means of gauging student performance (ranking) to determining student benefits. Seymour asserts that there are additional implications of changes in competencies include teaching that include learning and education research becoming valued as professional activities (Seymour, 1999).

Biggs' (1999) model of constructive alignment seems to provide a way in which the mismatch in what is expected by the lecturer and what is perceived by the students can be obviated by being explicit about the assessment criteria. Biggs (1999) model of constructive alignment suggests that there should be an explicit link between what is to be assessed and the learning outcomes. In terms of his model of constructive alignment "a good teaching system aligns the teaching method and assessment to the learning activities stated in the objectives so that all aspects of this system are in accord in supporting appropriate students learning" (Biggs, 1999, p. 11). A good teaching system will ensure that the learning outcomes are explicit; assessment tasks are designed to evaluate whether the outcomes have been met and whether they develop learning activities that will support the nurturing of the learning outcomes (Biggs, 1999). Airasian and Miranda (2002) state that the power of the curriculum is seen in its relation to goals, pedagogic practice and assessment. Good alignment between the three validates assessment results. When goals, pedagogic practice and assessment are not well aligned, the validity of assessment results are called into question (Airasian & Miranda, 2002).

Feedback from assessments has the potential to enhance learning if it is designed appropriately to promote learning. To enhance learning, Rust (2002) asserts that in addition to being prompt, feedback must engage students in learning by addressing how and why the student did not meet the outcomes as well as how to improve. Some suggestions made by Ramsden (2003) and Biggs (2003) include: distinctly clarifying the assessment criteria and providing constructive feedback on assessments; designing assessments that encourage and test conceptual understanding; discouraging large volumes of content and large workloads; creating the opportunity for students to be involved in selection of content and method of study and discouraging activities that reinforce rote memorization, mechanical formula substitution and routine procedural knowledge. Graded tests and examinations that are mostly summative in nature do not add value to student learning. This is especially true when no feedback accompanies the mark. Students are thus deprived of the opportunity to identify areas of strength and weakness and ultimately the opportunity to develop their learning (Rust, 2002). Chickering and Gamson state that,

> knowing what you know and don't know focuses learning. Students need appropriate feedback on performance to benefit from courses … in assessing existing knowledge and competence … opportunities to perform and receive suggestions for improvement … and at the end, students need chances to reflect on what they have learned, what they still need to know, and how to assess themselves (Chickering & Gamson, 1987, p. 1).

Seymour (2000) adequately captures what she calls the shift in focus of assessment from "valuing what we measure to measuring what we value" (p. 88) emphasising the role that assessment plays in driving the classroom experience. Seymour (2000) elaborates on this explaining that teachers need to know what they want to students to know and then to decide what kinds of assessments and activities will expose students and staff to the learning that has been achieved and to what extent they have achieved the outcomes of the module. She contends that assessments are viewed as *drivers of change* by proponents of learner-centred teaching and posits that feedback drives change in the teaching and learning process. In addition she asserts that the networks that are formed serve as a platform for sharing and discussion of pedagogy and assessment practices (Seymour, 2000).

While previously assessment was viewed as an objective and scientific representation of student performance that quantifies learner achievement, Shay (2003) contends that assessment as an interpretive social practice is beginning to take root. Furthermore, Shay contends that assessment is dependent on various factors for example, the relationship between assessor and student (the assessed), the learning context as well as the nature and purpose of assessment tasks. While assessment has traditionally been viewed as providing evidence for summative, diagnostic and formative purposes, its purpose is also to provide evidence for the evaluation of an academic programme from an institutional perspective (Shay & Jawitz, 2005).The value and power of assessment manifests in the influence it has on what is taught and how it is taught, as well as with what and how students learn. Given that, it becomes apparent that assessment has the power to sway how teaching and learning are approached as well as how students learn (Black & Dillon, 1998). Assessment then becomes a framework for evaluating the quality of teaching and learning as well the quality of teachers and students (Broadfoot, 1996).

Shay and Jawitz (2005) argue that assessment can be used to enhance teaching and learning but problematise the notion that assessment can measure the quality of teaching and learning. The shift in the notion of assessment from that of objective and scientific to social interpretation has brought about a change in how validity is viewed. From the objective view of assessment, validity is seen as a quantitative assurance that “the test measures what it is meant to measure” (Killen, 2003), while from a socially situated interpretative perspective, assessments are validated on the basis that they are fit for the purpose for which they are meant (Nitko, 2001). In the social interpretation perspective, alignment is a key component of assessment validation as well as its ability to: identify good and weak educational practice and to strengthen and reward good educational practice and develop weak practice (Shay & Jawitz). Bloom’s revised taxonomy provides a framework for expressing educational objectives that instructional practice intends students to achieve. The revised taxonomy provides a means to determine the alignment between educational objectives, activities, and assessments in the curriculum (Krathwohl, 2002). The exposition of the different levels and the four general knowledge categories (see Chapter 2) enables teachers to match tasks and questions with educational objectives and assessments and to ensure that students are being taught and assessed at the correct level (Raths, 2002).

3.9 Factors Influencing Success in the Mathematics Modules for Engineers

Understanding what drives students to be successful can be helpful in influencing how lecturers approach teaching and learning mathematics for engineering students (Rea, 1991). The term success means different things to different people and while it is acknowledged that there may be several definitions and interpretations of the term *success,* in the context of this study, *success* is defined as a pass (a final mark of at least 50%) in the ME module.

3.9.1 General perceptions of factors affecting success in mathematics. The recent document released by the CHE, *A Proposal for undergraduate curriculum reform in South Africa,* states that of the many factors that affect student performance in higher education, finance, affective factors and academic factors rank high on the list (CHE, 2007; CHE, 2013). The academic factors identified refer to the articulation gap and student under-preparedness as dominant factors which affect student success. Student under-preparedness is commonly stated as a key factor in high attrition and low success rates in higher education (CHE, 2013; Croft & Ward, 2001; DoE, 1997; Hawkes & Savage, 2000; Fisher & Scott, 2011; Scott, 2007). The articulation gap is acknowledged to be the mismatch between the prior knowledge that students are required to have in place upon entry to university and that which they actually have in place upon exiting the schooling system. Scott (2013) claims that higher education institutions have the responsibility to educate students who enter their portals and that the high failure rates can be attributed to systemic factors. There seems to be a mismatch between teaching and learning on the one hand and students' prior knowledge on the other. Scott suggests that higher education, review its structures, assumptions and practices underlying teaching and learning and emphasizes that the mismatch is as a result of the level of academic competence which lecturers assume that students have in place upon entering higher education, and which they apparently do not. The current structures, assumptions and practices are based on a student cohort that is vastly different from those of today (Scott, 2013). While the root of the problem is claimed to be located in the schooling system, it is acknowledged that little progress is expected to be made in that regard in the near future. It therefore rests with higher education to work with factors within its control to enhance student success whilst simultaneously maintaining good academic standards (CHE, 2013).

Diverse student composition, lack of preparedness, variations in assessment and quality of teaching, could potentially explain student under performance (Fisher, 2011). Student success is likely to improve if an extended curriculum is offered and restructuring flexible entry points and progression paths (CHE, 2013; Fisher & Scott, 2011). This can be done if higher education institutions acknowledge the students that they have rather those they ought to have, which means understanding the current student profile (Scott, 2013). The undergraduate proposal identifies curriculum structure as a framework that constrains or enables effective teaching and learning. A recommendation has been to extend the duration of the core degree programmes to narrow the articulation gap in the higher education sector (CHE, 2013). Student under preparedness is seen as relative in that while the prior knowledge assumed for entry into higher education may render students underprepared for entry at some levels, they may be prepared for other levels that make different assumptions about students' prior knowledge. Student under preparedness therefore does not mean that students are not capable of learning in higher education. Hence while students' assumed knowledge may not be adequate for a certain level it may be so for another level of entry. A suggestion is thus to provide differential entry points into higher education (Fisher & Scott, 2013).

Fisher and Scott (2011) claim that building the capacity of the teaching and learning process to understand the student profile and challenges enhances the potential for student success. One of these challenges they identify is that of large classes which can be addressed with the assistance of technology. However addressing the diversity in students' educational backgrounds, is a far more complex problem than that of large classes, especially considering the wide range of inadequacies that act as inhibitors in the learning process. Croft and Ward (2001) note the wide range of mathematical competencies characteristic of incoming students that are a challenge to those teaching mathematics. They describe mathematics as a linear, hierarchical subject which requires the development of new ideas that are built on existing ones through assimilation. The gap between weak and bright students is extreme and any single approach disadvantages either the weak or the bright students. With weak students, lack of understanding results in students copying notes with little or no understanding leading to a dearth of incentive and motivation to attend lectures. Teaching and learning in higher education are thus controversial yet complex issues and while a single teaching and learning approach may be a solution in that it could well work for some students, it may not be appropriate for all students. The recommendation is that concerns of inadequate academic preparation, diverse learning styles and the articulation gap be addressed though a flexible curriculum framework that provides differential entry points for students depending on the level of their academic preparedness (Fisher & Scott, 2011).

Fisher and Scott (2011) suggest that the improvement of teaching and learning should incorporate the professional development of academic staff to improve their academic qualifications and professionalise teaching in higher education since they contend that under prepared students, large student numbers and diversity in educational background present challenges for staff who lack the training and know-how to support teaching in a challenging environment. As such the suggestion is that teaching and learning policies be institutionalized to provide access to educational training for teachers in higher education (Fisher & Scott, 2011). This is supported by the SAHEI who have already put in place policies which require new and junior lecturers to register in the university induction programme, which provides the educational training necessary for teaching in higher education in the current context.

Hawkes and Savage's (2000) report on factors affecting student success, notes the decline in mathematical competencies and under-preparedness of students entering mathematics-related courses of study at universities in the UK. They found that this was consistent with reports across the UK that highlighted the state of mathematics education and exposed the lack of mathematical preparedness for the study of mathematics in higher education. Consequently student under-preparedness has become problematic for those teaching mathematics courses at universities especially considering the diverse range of mathematical performances of students in high school. These findings are consistent with those of the CHE (2013), Fisher and Scott (2011) and Scott (2013) who base their contentions on data from South African HEIs. Students entering higher education for the first time should undergo diagnostic testing so that the deficiencies of individual students and the cohort can be identified with the aim of developing follow-up measures to address the deficiencies (Hawkes & Savage, 2000). This would provide the opportunity for academic staff to design their modules and identify appropriate interventions to enhance teaching and learning (Hawkes and Savage, 2000).

3.9.2 Student perceptions of factors affecting success in mathematics. Determining what students perceive as being effective teaching and learning strategies in mathematics can be used to improve the same with a view to enhancing student success (Dean, 1998). In the School of Applied Psychology at the University of Griffith, Australia, Lizzio *et al.* (2002) examined student's perceptions of academic environment, methods of study and academic performance using higher order path and regression analysis. They reported a high correlation between academic environment and academic performance, more so than prior performance at school. Students' responses showed that they were encouraged to adopt surface approaches to learning where there were heavy workloads and inappropriate assessments while perceptions of good teaching encouraged them to adopt deep approaches to learning. Larose and Roy (1991) conducted a study of 1408 college students using a Likert-type questionnaire to test the hypothesis that the students' grade point average was the best predictor of success. Their findings could be categorized and reported under at-risk students and the total general student cohort. The data illustrated that the grade point average (GPA) was a good predictor of success for the general cohort but personal attributes were an even better predictor of success for high-risk students thus indicating that different groups of students may achieve success in different ways. This confirms the view that a one-size-fits-all teaching and learning approach is not conducive to student success. Teaching and learning must be approached using a combination of strategies if teaching is to meet the learning needs of students to ensure a match between the strategies adopted and what is effective for students in terms of academic success.

Schonwetter (1993) studied the attributes of effective teaching in college classrooms. He claimed that effective teaching could be determined by measuring specific student outcomes identified in the literature. These include cognitive and affective factors such as enhancement of problem solving skills, positive student evaluation, increased attention, motivation, satisfaction and competence. Using tests that were valid, reliable and objective, he found that a combination of teaching factors could be attributed to student success. Schonwetter lists student perceptions of success, locus of control and instructor's articulation in the classroom as three factors that have implications for student success. For example, students themselves may not attribute their academic success to their own effort (external locus of control) but rather to the kind of teaching that they are exposed to. Wernstein (2004) reported on a study of university students who had previously failed mathematics but were highly successful in a remedial mathematics course. His investigation of the reasons for students' success revealed that the teacher and students had negotiated teaching and learning through a consensual give-and-take understanding. Prior to the negotiation, the teachers wanted to develop conceptual understanding whereas the students aimed for procedural understanding. The give-and-take resulted in constructive development of procedural and conceptual understanding. This study highlights the importance of communication between teachers and students in developing a positive teaching and learning environment. Kalman (2008, p. 3) suggests that "many students were failing science not because they lacked the ability to understand the courses, but because the courses were not meeting their needs".

Athony's (2000) study focused on identifying factors that contributed to the success of students. The perceptions of lecturers and students regarding factors influencing success were evaluated. The study was conducted with first year mathematics students using qualitative data that was collected from students and lecturers. She found that motivation was an important factor in student success, and she recommended further investigation into student's effort, volume of work, help-seeking behavior and active learning strategies. Her findings suggested that teaching and learning are not independent processes and that the relationship between teaching, learning and the context in which this occurs require inspection. Exploratory open-ended and Likert- type questionnaires and interviews were used in three phases. The first two phases concentrated on lectures and students across all the disciplines in the university, while semi-structured interviews were conducted with ten first year students in mathematics. The open-ended questions required students, lecturers and tutors to list five factors that were central to their success and five factors that contributed to their failure. The factors identified in phase one, were broadly categorized in accordance with those of Killen (2003) and showed that while students placed more emphasis on factors such as lectures and course design than did lecturers, the lecturers placed greater responsibility on students for failure than did students. Phase two of the study was the Likert-type questionnaire in which there was consensus that self-motivation was the most likely factor influencing student's success. Other factors found to be influential to student success were: completion of assessments, access to high quality support; attendance at lectures; good lecture notes which included step by step explanations and clear expressions of his/her thinking (Killen, 2003).

3.10 Similar Studies Using Bernstein as a Framework

Bernstein's model of the pedagogic device discussed in Chapter Two was used as the analytical framework to analyse the ME module on the basis of recontextualisation, and classification and framing. International and national studies using this framework are presented next.

3.10.1 Recontextualisation. The studies that are described show that ideological principles influence pedagogic practice and the sociological message that is conveyed by curriculum documents and pedagogic practice. This is exemplified by Morais and Neves (2012) in their study of the disciplines of science and science education. They describe both disciplines as vertical discourses with science having a hierarchical knowledge structure and science education, a horizontal knowledge structure. They examined the recontextualisation of knowledge from the guidelines in the curriculum document through to the classroom context. There is a distinction between the *what* of teaching and learning (the content) and the *how* (pedagogic practice) of teaching and learning which requires a 'jump' from the hierarchical discipline of science to the horizontal discipline of science education. Pedagogic practice essentially determines the level of conceptual demand of the module. Morais and Neves (2012), in their study, sought to determine if the level of conceptual demand in science education correlated with the different conceptual levels of the vertical discourse in the transmission and acquisition of scientific knowledge. They defined conceptual demand as the level of complexity of the teaching and learning process with regard to scientific skills. Teaching and learning that encouraged memorization and low level comprehension were regarded as low level skills while application of knowledge, analysis and a high level of comprehension marked high levels of complexity. Their findings showed a correlation between teachers' pedagogic practice, level of conceptual demand and students' scientific learning. That is recontextualisation occurred at the level of the classroom where the teacher's ideological beliefs about students' abilities in science influenced the level of conceptual demand of the lesson.

Similarly, Ferreira, Morais and Neves (2011) found that the ideological views of curriculum designers influenced their decisions on curriculum design. In their study they sought to determine the ideological views of curriculum designers and to what extent the ideological and pedagogical principles of the designers of the curriculum influence the sociological message of the curriculum documents? Their approach to the study was a mixed methodology using interviews and document analysis. The study was conducted in the discipline of Natural Sciences at middle school level and focused on four ideological educational objectives: education for all and teachers' autonomy (general educational objectives) and scientific literacy and science construction (objective specific to the discipline). They found that authors of the curriculum have distinct ideological views that influence curriculum decisions. The views of authors with higher level status were evident in the social message transmitted by the curriculum as they indicated teachers should have greater autonomy and emphasized education for access for all. By this they acknowledge that this means success for some. Lower status authors emphasized lower autonomy for teachers and education for success for all which means that the textbook was more prescriptive giving teachers less control over aspects of the teaching and learning process. In effect recontextualisation occurred at the level of curriculum design and influenced the social message conveyed by the curriculum.

The findings of a study by Geirsdóttir's (2008) concur with those above. In his study he examined lecturers' ideas of disciplinary curriculum decision-making at the University of Iceland. His central argument in his paper is that the curriculum forms the nucleus of higher education. He contends that the lecturers' interpretations of the curriculum manifest in how disciplinary knowledge is transmitted, how students should acquire it and who gets access to it. Therefore the research aspired to understand how university teachers understood teaching and learning. The parallels drawn between the University of Iceland and the SAHEI showed increased enrolment in higher education within short time frames as well as in the academic freedom that universities afforded their academic staff in terms of research and teaching. The findings show that teachers modeled their teaching on the way they were taught and brought with them the local culture of the universities they studied in, each having been inducted into a discipline through regulative and instructional discourse. This study showed that ideology was at play when teachers recontextualised knowledge at the classroom level.

While the studies discussed above describe international research on recontextualisation, the study by Case (2013) is an exposition of a project viewed from the perspective of the South African context. In her project: *Cracking the code: widening access to science and engineering education*, Case points out that in South Africa there is an increase in the number of students from disadvantaged backgrounds opting to become engineers. While South African higher education institutions succeed in attracting the best and the brightest into engineering, the failure rates are high with the blame placed squarely on the quality of schooling provided by high schools. Mass schooling world-wide has shown that the quality of high school education throughout cannot be guaranteed and that higher education needs to take cognizance of the student profile and create student experiences that enhance the success of students. Making reference to the ‘Two Cultures’ debate, Case refutes the vision of science as a ‘democratic zone’ in South Africa, explaining that traditionally science and engineering were the domain of ‘middle class white male’. At the SAHEI, the ‘democratic zone’ is a vision which has not materialized. The facts are simple: while access to disadvantaged students has improved, epistemological access seems to evade the ‘non-traditional’ student as they do not share the successes of the traditional student. Case’s project is grounded in engineering education within the critical realist perspective offered by Roy Bhaskar, and draws on the work of the social theorists like Pierre Boudieu, Basil Bernstein, and Margaret Archer to justify the claims that engineering programmes serve to reproduce social inequalities (Case, 2013).

Drawing on the constructs of structure, culture and agency, Case points to the interaction between the three constructs that reproduce social inequalities. Elaboration of the role of structure, culture and agency in maintaining the status quo reveal how the recontextualisation of knowledge structures in engineering curricula create obstacles that inhibit progress and ultimately success in engineering. Pedagogical practices, which are seen as part of the recontextualisation of knowledge structures, are based on students having or being able to pick up the tacit understandings required for success in engineering. In addition, the institutional context is seen as promoting a culture of inclusion and exclusion where those who fit the ‘ideal student’ that pedagogic practice is predicated on, are the included and benefit while those who do not form those excluded and are disadvantaged.

Similar findings are described by Hoadley (2006), who in her study of social class differences in a South African educational context, developed a model for investigating the pedagogic variation based on social class differences. In accord with Bernstein’s theories, she claimed that students from varying social groups entered the educational arena differently predisposed to success. The theoretical model that Hoadley adopted consisted of three dimensions based on Bernstein’s models of pedagogic discourse, classification and framing and the instructional form of the pedagogy. The study focused on the orientation to meaning as a critical factor of social class that influenced the learning experience. The findings of her study show how different meanings are reproduced via the pedagogical processes that are present in different social class educational contexts and revealed that working class students were disadvantaged by the pedagogic practice of the education system.

3.10.2 Classification and framing. While proponents of progressive teaching approaches claim that relevant real-world examples (denoting weak classification of content) enable students to build on existing knowledge and develop higher levels of abstraction and generalization (Herrington, Reeves, Oliver & Woo, 2004), others claim the contrary (Case, 2011; Maton, 2009; Muller; 1998; Bennet, 2002). Studies that illustrate the dichotomy are discussed below.

To determine whether real-world problems enhanced cumulative learning and led to the development of higher levels of abstraction, Bennet (2002) conducted a study on postgraduate Masters students enrolled in a programme designed to train instructional designers in Wollongong, Australia. The students were given ‘authentic’ case studies of instructional design projects with each case comprising 15 000 unedited words of interviews with three interviewees. Students had to respond to questions which required them to think beyond the context of the cases which were then analysed using Bernstein’s languages of description. Findings of the study show that exposure to relevant, real-world examples did not enable cumulative learning and that the students’ understandings remained rooted in the context of the problems. This contradicted the aim of authentic learning tasks which was to enable cumulative learning and to develop higher levels of generalization and abstraction.

The findings of Jobér’s (2012) study concur with those of Bennet (2002). Jobér conducted an ethnographic study of 14 and 15 year old students over a five week period in a unit of Physics in a Swedish compulsory school. The aim of the study was to provide a complex and comprehensive analysis of inequalities in education. Her study was motivated by a review of studies which revealed a correlation between students from low social class background and low achievement in science education. Furthermore, she noted that despite the focus on creating equal educational opportunity for all students, social class differences are still reproduced in school. This low achievement resulted in students from low social class being excluded from what is considered to be highly-valued education and subsequently extended to the work environment where they were excluded from highly-valued positions in society. Bernstein's three message systems were analysed using the concepts of classification, framing, recognition and realization rules as the theoretical framework. Interviews, observations, student questionnaires and field notes were used to collect data. The data was analysed using Bernstein's concepts of classification and framing, recognition and realisation rules as well as regulatory and instructional discourse. Analysis of the data revealed that activities in the Physics classroom led to the reproduction of social inequalities that were evident in society. Jobér found that while weakly framed sessions in the laboratory provided students with some degree of freedom, those were not beneficial to students who were unable to recognize or realize what needed to be done. As the instructional discourse is embedded and thus driven by regulatory discourse, the regulatory discourse was found to impede student learning.

In their article titled *Three educational scenarios for the future: lessons from the sociology of knowledge,* Young and Muller (2010), claim that little attention is given to currently and commonly used terms such as globalization and knowledge societies which are terms that unintentionally disguise issues underlying social change. In support of this they claim that an analysis of current trends in educational policy and current schooling highlights a mismatch between the two. Furthermore the evidence shows the resistance of schools to adapt to educational policy by perpetuating dominant practice in order to maintain the status quo. Kress (2008) argues that social changes bring to the fore questions of appropriateness of dominant myths about education and their prevailing dominance despite them being outdated, assumptions that the student profile is reflective of homogeneity, and ontological and epistemological assumptions underlying the security of knowledge. Taking cognizance of social changes, Young and Muller coined the term 'futures thinking', a concept based on the assumption that social changes on a global level are inevitable and in the best interest of humanity. The concept of 'futures thinking' extrapolates current social change into the educational arena and identifies three possible curricula that aptly capture the concepts of Futures Thinking (Young & Muller, 2010).

The studies described in this section seem to indicate that progressive teaching approaches, which encourage weak classification of knowledge and weak framing over selection, sequencing and pacing of content, and which claim to enhance learning and development of abstract understanding, have an adverse effect on the same.

3.11 Conclusion

In this chapter, I presented a review of the literature on theories of teaching and learning. The meaning of the term ‘curriculum’, as expounded by several authors was discussed and a definition of the same for this study was established. Following this a discussion of teachers’ personal beliefs and theories about mathematics and mathematics teaching and learning and their influence on the approaches that teachers adopted in the class ensued. A brief overview of some approaches to learning was presented as was a review of approaches to teaching and learning mathematics particular to engineering education. This review highlighted some current dominant practices used in engineering classrooms globally. The exposure to various studies revealed that in engineering contexts the constantly changing landscape in engineering and higher education, the changing student profile and research in engineering education are influential in shaping how teaching and learning is approached. Furthermore these studies highlight teaching and learning approaches from a sociological perspective that has fueled research in engineering education. The literature reveals that in some institutions engineering education is under constant review to enhance teaching and learning, it also exposes that traditional approaches are rife in engineering education, particularly in the mathematics classrooms of engineering students. A discussion of assessment, successful factors and similar studies followed. The next chapter presents a detailed description of the methodological considerations and procedures followed in this study.

Chapter Four
Research design and methodology

The motivation for this study was to develop an understanding of teaching and learning in a first year mathematics module for engineering students. To that end the role of mathematics in engineering is explored, as are the teaching and learning approaches adopted and motivations for the approaches assumed. The chapter begins with an exposition of the philosophical orientation to this study and the use of the case study as the methodological approach. The next section describes and rationalises the plan that was designed for "engaging in a systematic inquiry" (Marshall & Rossman, 2011, p. 56) to bring about understanding of teaching and learning in the mathematics module. A description of the research methods, their appropriateness to the research questions and the selection of research instruments are presented. Subsequent to this is a detailed description of the methodology of analysis and interpretation of the evidence. Finally the conclusion presents a summary of the chapter. A discussion of the paradigmatic stance of this study follows.

4.1 Paradigmatic Orientation of the Study

Scientific inquiry operates within a set of beliefs, referred to by Kuhn (1996) as paradigms. Since its inception, the term paradigm has been variously defined. Guba and Lincoln defined the term paradigm as a "basic belief system or world view that guides the investigator, not only in choices of method but in ontologically and epistemologically fundamental ways" (1994, p. 105). More recently, Neumann (2006) describes 'paradigm' as a "general organizing framework for theory and research that includes basic assumptions, key issues, models of quality research and methods for seeking answers" (2006, p. 81). Guba and Lincoln (1994) assert that "questions of method are secondary to questions of paradigm" and that differences between paradigms run deeper than differences in philosophies as "implicitly or explicitly, these positions have important consequences for the practical conduct of inquiry, as well as for the interpretation of findings" (p. 112).

A research paradigm comprises the ontological and epistemological assumptions and influences the choice of methods that are used and the method and style of interpretation derived from the data analysis. Since research provides answers to questions about knowledge and involves ways of generating data and values, paradigms are also concerned with matters of methodology and axiology (Cresswell, 2003). The methodological approach explains how knowledge will be generated to answer the research question, while axiology addresses the values that are involved in the choice of paradigm. Paradigms thus involve issues of epistemology, ontology, methodology and axiology to answer questions of the nature of knowledge or truth, the nature of reality, the procedures that will be used in conducting the research and the nature of values. Paradigms are thus central to social science research as they influence the development of the research question, research design and selection of methods germane to the research. This research is located within the pragmatist paradigm as this resonates with my ontological and epistemological assumptions. For me, the nature of reality is dynamic rather than static, neither spiritual nor physical but a process that is derived from experience in the environment. This means that reality is relative, and the only certainty is change. The nature of knowledge, from the pragmatist stance, claims that truth is not absolute but relative as it is only held for as long as it is supported by available evidence. The pragmatist's view is that something has value or is deemed to be good if it leads to achieving the desired end. I start my rationalisation of this philosophical orientation with a discussion of the qualitative-quantitative debate.

Until recently the two dominant paradigms in research were the qualitative and quantitative paradigms. The deliberation of how best to approach this study led me to the philosophical arguments of the proponents of each of these paradigms. Paradigmatic purists have, traditionally engaged in the 'paradigm wars' (Johnson & Onwuegbuzie, 2004) claiming the superiority of one paradigm over the other as well as their incompatibility. These two approaches to research have been viewed as distinct and incompatible paradigms in the field of educational research (Shaffer & Serlin, 2004). Morais and Neves (2010) mention that distinct approaches are often required in situations requiring distinct questions to be addressed. Studies show that different approaches can be used at various stages of a single study and assert that they can assume equal or unequal statuses in the study (Tashakkori & Teddlie, 1998). Elaborating on this, Tashakkori and Teddlie explain that qualitative data can be used to develop hypotheses for quantitative research while quantitative analysis supports the identification of subjects for qualitative studies. While the qualitative and quantitative paradigms reflect many similarities, qualitative and quantitative purists claim that the two paradigms differ on fundamental issues of ontology, epistemology, axiology and methodology (Onwuegbuzie & Leech, 2005).

Quantitative research views the world as a “fixed, single, agreed upon, or measurable phenomenon” (Merriam, 2002, p. 3). Proponents of quantitative research (quantitative purists) are generally aligned with a positivist philosophy. The quantitative purist views social observations in a scientific light as though they are analogous to how physical phenomena would be viewed. They are convinced that reliable and valid causes of social science results can be gained through objective, scientific study, that purport to be time, context and value-free. This requires social science (in this case educational) researchers to base their analysis on empirical data that is obtained through unbiased inquiry. This can be accomplished by the researcher remaining emotionally detached and free from the phenomenon under study (Johnson & Onwuegbuzie, 2004, p. 14). While the quantitative approach was appropriate for generating data that would lend support to the research questions, the data that was required to answer all three research questions validly and reliably required data collection methods that were not solely associated only with quantitative research methods. The use of data collection methods to ensure validity necessitated the use of quantitative as well as qualitative methods as this study sought to explore how teaching and learning was approached and to interrogate why such teaching and learning approaches were adopted.

Qualitative purists argue that research cannot be value, time or context-free. Qualitative researchers reject the notion of a single reality as they acknowledge that there are multiple constructions and interpretations of reality and that understanding those interpretations is fundamental to research of this type (Merriam, 2002). Johnson & Onwuegbuzie acknowledge this stating that multiple-constructed realities exist, that fully differentiating causes and effects are impossible and that logic is deductive (2004). Qualitative research is concerned with the idea that individuals construct meaning of their world through social interaction with it. Whether analyzing documents, experiences of people or interactions and communication of and among people, qualitative research seeks to unravel and provide a wealth of insight into how people make sense of the world (Kvale & Flick, 2007). A separation between knower and the known is not feasible since the only reality is that of the knower (Guba, 1990).

Qualitative and quantitative purists site irreconcilable differences between their approaches, labelled by Howe (1988) as the incompatibility thesis, which propagates the notion that “accommodation between paradigms is impossible ... [as] we are led to vastly diverse, disparate, and totally antithetical ends” (Guba, 1990, p. 81). Mixed methods research, viewed as the third paradigmatic approach to educational research, is the paradigm that occupies the middle ground between qualitative and quantitative research. This paradigmatic approach focuses on the strengths of qualitative and quantitative methods that can be drawn on to enhance the research. Johnson & Onwuegbuzie (2004) suggest that researchers should be concerned with how each of these approaches can best be used together to complement the study. Research itself is becoming interdisciplinary requiring methods that complement each other creating the need for researchers to be versed in several methods if they are to promote collaboration and communication between scholars as well as good quality research.

Mixed methods research endorses the idea that researchers can use a mix of methods, from traditionally known paradigms, if the mix can enhance the quality of research being done. According to Johnson and Onwuegbuzie (2004), “The goal of mixed methods research is not to replace either of these approaches but rather to draw from the strengths and minimize the weaknesses of both in single research studies and across studies. (p. 14 - 15). They explain that both epistemologically and methodologically there is no reason why a qualitative researcher holding a particular logic of justification cannot use a method traditionally aligned with quantitative research as epistemology does not dictate methods of data collection. Purists tend to hold constricting definitions of what constitutes qualitative or quantitative research that tie in with their philosophy (Johnson & Onwuegbuzie, 2004). Whilst they acknowledge that a mixed methods approach is not a solution to the quantitative/ qualitative debate, they suggest that it uses a philosophy and methods that support a workable solution using the understandings gained from qualitative and quantitative research.

I acknowledge that both qualitative and quantitative research, are useful and hence for me as the researcher, the boundaries between the two paradigms are weak. It is difficult, considering the complexity of human nature, to place myself completely on one side or the other. Johnson and Onwuegbuzie suggest that "if you visualize a continuum with qualitative research anchored at one pole and quantitative research anchored at the other, mixed methods research covers the large set of points in the middle area" (2004, p. 15). The mixed methods approach privileges methods that are considered most appropriate to the collection of data that will best answer the research questions. In this research, the methods that were considered most appropriate were drawn from both the quantitative and qualitative approaches, resulting in a mixed methods approach to the study. Two paradigms that occupy the middle ground are critical realism and pragmatism.

Since critical realism occupies the middle ground, the ontological stance is dependent on its position. Positivists (quantitative paradigm), believe in a single reality "that can be measured reliably and validly using scientific principles", while interpretivists (qualitative paradigm) believe in multiple realities which construct different meanings for people according to the lens through which the research is conducted (Onwuegbuzie & Leech, 2005, p. 270). Critical realism, assumes the existence of an external reality that is independent of what we think about it (Zachariadis, Scott & Barret, 2010) so implying that knowledge has the potential to be flawed and that the notion of an absolute truth is not possible. Critical realism bridges the dualism between the objective and subjective views of reality (Dobson, 2002). The critical realist identifies two dimensions of knowledge, the transitive and intransitive dimensions. The transitive dimension (theories used to understand the phenomena) is that in which the observation of reality is value laden and transient whereas the intransitive dimension (the phenomena under study) is one that is static and in which reality is independent of our account of it (Sayer, 2000; Dobson, 2002). The transitive dimension acknowledges that the researcher comes into the research with prior theories and thus cannot claim that knowledge is absolute (Miller & Tsang, 2010).

Another paradigm occupying the middle ground is pragmatism. Johnson and Onwuegbuzie (2004) support pragmatism as the philosophical partner to mixed methods research. Ontologically, the pragmatic paradigm embraces "multiple methods, different world views, and different assumptions, as well as different forms of data collection and analysis in the mixed methods study" (Cresswell, 2003, p. 12). The pragmatist acknowledges that values play a role in the interpretation of the results. Pragmatists accept subjective and objective points of view, endorsing a mixed methods approach to data collection. In addition, pragmatism advocates the use of inductive and deductive logic, both of which are used in this study, to explain the data (Onwuegbuzie, 2002). Powell (2003) reasons that pragmatism as an epistemology stands in contrast to prevailing positivist and anti-positivist epistemologies:

> Positivism emphasizes the objective …properties of a … reality independent of observation … anti-positivism emphasizes the creative role of active, subjective participants, [with no] … privileged claim on truth. Pragmatism, on the other hand, rejects positivism, on grounds that no theory can satisfy its demands … and rejects anti-positivism, because virtually any theory would satisfy them. As such, the pragmatist proposes to … solve … problems. (p. 884)

The mandate of science, according to a pragmatist, is not to determine truth or reality but rather to develop an understanding that will facilitate the ability to solve problems. Pragmatism rejects the notion of an either-or dichotomy with regard to methods, logic and epistemology (Tashakkori & Teddlie, 1998) and embraces the use of both in a single study. Explanations that are most appropriate to achieve the desired outcomes are promoted. The focus of this research is to gain an in-depth understanding of how and why teaching and learning is conducted the way it is and its meaning for those who are a part of the context. The use of document analysis, interviews, observations, questionnaires, experiences and interactions provides ways to generate, document, represent and analyse data as a means to understand and describe social phenomena. Access to the above-mentioned data sources in a natural context that give "room to the particularities of them and the materials in which they are studied" and where "concepts … are developed and refined in the process of research" (Kvale & Flick, 2007, p. x). The researcher brings to the process his or her own reflexivities (Kvale & Flick, 2007), and forms an important part of the research process. Pragmatism as a philosophy resonates with my world view and is thus the privileged orientation to the study. After looking at the research questions through the lens of a pragmatist, I realised that a mixed methods approach was most appropriate in the context of the research.

4.2 Research Design and Methodology

Having established the paradigm that informs this study, the choice of research methodology considered most appropriate for the research had to be made. This section of the dissertation discusses and justifies the methodological approach that will be taken and methods that will be used in the data collection process. In any research project, it is necessary to establish at the outset, the phenomena to be studied as well as how the data that is needed to provide answers to the research questions will be generated (Miles & Huberman, 1984). The methodology reflects the reasons why the researcher has chosen to do the research in a particular way and reveals the nature of the research questions and the philosophical stance guiding the research design (Burton, 2002). The researcher's ontological and epistemological standpoints must be transparent in selecting the methodology without having to choose either a qualitative or quantitative approach. The choice of methodology and methods lends credibility and robustness to the research design (Silverman, 2007, p. 112). Research methods by themselves do not dictate whether the approach to research is qualitative or quantitative as they lend themselves to use in both (Silverman, 2005). They take on the implication designated them according to the methodology used. This study seeks to provide a deep understanding and analysis of teaching and learning in a first year mathematics module for future engineers. So, in attempting to find a methodology that best suited the objectives of this study and methods that could be used to generate data that is relevant, I had to consider several key aspects of a study such as the research questions driving the study, consideration of the data that will best answer the research questions, the data sources that would enable the collection of such data, the context in which the study takes place as well as my own beliefs, values and attitudes (Burton, 2002).

McMillan and Schumacher (1984) cited in Merriam (1988), claim that "the purpose of most descriptive research is limited to characterizing something as it is … There is no manipulation of treatments or subjects; the researcher takes things as they are" (Merriam, 1988). After considering the descriptions provided for what constitutes a case study using the perspectives of several well-known authors in the field of educational research, I identified the case study as most appropriate for the purpose of this study (Bassey, 1999; Cohen, Manion & Morrison, 2000; Merriam, 1988; Silverman, 2009).

My study, located in the field of engineering education, falls within the ambit of research in higher education and deals with human experience. Teaching and learning mathematics to future engineers must be understood within this context. Social and cultural contexts cannot be ignored as they are embedded in human experience (Burton, 2002). In other words the research methods had to be consistent with the values espoused by the study, the researchers own beliefs and the research methods chosen. It was also necessary to provide information that provided epistemological transparency (Burton, 2002, p.8), to allow access to the influences that led to the discovery of the phenomenon under study. According to Burton (2002) objectivity in a study is achieved through internal consistency, coherence and robustness (that refers to how strongly the study resonates with various views related to it).

4.3 Case study as the Methodological Approach to the Research

Merriam describes the case study as “an intensive description and analysis of a phenomenon ... [and] is a bounded, integrated system ... concentrating upon a single phenomenon ... this approach seeks to describe the phenomenon in depth” (Merriam, 2002, p. 8). The research, seeks to provide an in-depth description and analysis of teaching and learning in the ME module in the engineering curriculum. Knowing how teaching and learning is conducted and understanding why it happens the way that it does guided me towards the choice of a case study as an appropriate research approach to this study. The features of a case study describe it as an integrated system bounded in time, space, location and components (Merriam, 2002). At the outset, the boundaries and the unit/s of analysis of a case study need to be defined together with an established research problem “geared to specific features of the case” being researched (Silverman, 2009, p. 138). The researcher has minimal control over the research context and attempts to collect data in an unobtrusive way that does not interfere with the phenomenon under review (Merriam, 1988). In this research the phenomenon was a single module, taught in a single site by three academics. It was bound in time, bound by academics lecturing the module and bound by those who set the assessments. I was an observer in lecturers and tutorials in their natural context as part of my professional responsibi lities. In the light of the above points the case study, as a methodology, seemed to have the best fit in terms of its appropriateness to answer the research questions.

A case study requires multiple methods to truly capture the case in depth. To identify appropriate methods, I set up a list of the same, as suggested by Mason (1996, p. 19), and looked at how each one was appropriate and relevant in providing the data that was necessary to answer the research questions by asking (a) What are the possible data sources that are accessible?, (b) What kinds of data can each generate and (c) Which research questions will the data answer? Scrutinising the research questions enabled me to identify the kinds of data that I would need to generate and asking where I would be able to get this data from pointed me to the data sources. Working backwards, I established that the data would answer the research questions. For example, to generate data that would enable me to understand what motivated the way teaching and learning was approached I required interviews with module lecturers. Tracing through the list yielded the data sources (documents, lecturers, tutors, students, lectures, tutorials and assessments) and methods (interviews, observation, questionnaires and document analysis) most appropriate for generating the data needed. The data needed to answer these questions would have to be collected in the following ways: (a) observing how teaching was approached during lectures and tutorials and (b) interviewing the lecturers to determine why used those particular approaches to teaching in the ME module and (c) collection of documents that would reveal the role, nature and content of the ME module and (d) interviews and questionnaires with students to determine their perceptions of how well they learned the mathematics in the ME module and alignment between the various components of the module.

The findings from analysis of the data provided rich data that were used to answer the key research questions. The data provided deep insight into teaching and learning in the ME module. The research questions were open-ended and orientated in a way to allow findings that were not initially anticipated, to emerge. In qualitative research, interviews are used with a small number of respondents who are asked open-ended questions. The three lecturers responsible for teaching and learning were interviewed to determine why they approach teaching and learning the way they do. This was crucial to understanding what motivated the way academics approached teaching and learning in the ME module. Questionnaires were administered to students registered for the ME module to determine whether the content and teaching included examples relevant to engineering contexts, alignment between lectures, tutorials and assessments. This data contributed to my understanding of how teaching and learning is approached in the ME module.

4.4 Data Collection Methods

The first research question is concerned with the role of mathematics for engineering students at the SAHEI. This research question requires empirical evidence as it focuses on the ME module in terms of its content and how it fits into the engineering curriculum nationally and globally. Determining the role of the ME module initiated an appraisal of the documents that govern curriculum and its content and an interrogation of those members of staff tasked with managing the curriculum in the ME module. This necessitated the use of the following data collection methods:

- Documents (Washington Accord, ECSA, SAHEI College of Agriculture, Engineering and Science Handbook).
- Interviews with mathematics and engineering academic staff involved in the module

4.5 Data Collection: Strategies and Instruments

Interviews and observation are regarded as foreign intrusions into the environment that is under scrutiny as they introduce limitations such as access and cooperation. Documents, on the other hand, are not created solely for the purpose of research and hence provide an expedient source of data that is easily accessible and which transcends issues of cooperation (Merriam, 1988). A synopsis of the data corpus is illustrated in Table 4.1.

Table 4.1

Synopsis of Data Corpus and Analysis Methods

Research question	Data collection strategy	Research participants	Data collection instrument	Information sought	Data capture/ searching method
Official recontextualisng field					
RQ1	International signatory documents	Washington Accord	Not applicable	Classification and framing of relationships	Download from ECSA website
	Professional body documents	ECSA	Not applicable	Classification and framing of relationships	Download from ECSA website
Pedagogic recontextualising field					
RQ1	Semi-structured interviews	Lecturers in the ME module	Interview schedule	Classification and framing of relationships. Understanding the role of mathematics in engineering	Audio recording
	Semi-structured interviews	Head of school of mathematics	Interview schedule	Classification and framing of relationships Understanding the role of mathematics in engineering	Audio recording
	Module documents	Module template	Not applicable	Classification and framing of relationships	Not applicable
Field of reproduction					
RQ2	Semi-structured interviews	Lecturers in the ME module	Interview schedule	Lecturers approach to teaching and learning Perceptions of enabling and disabling factors in students success or failure	Audio-recording
	Semi-structured interviews	Students	Interview schedule	Lecturers approach to teaching and learning Perceptions of enabling and disabling factors in students success or failure	Audio-recording
	Observation	Lecturers	Field notes	Lecturers approach to teaching and learning	Audio-recording and field notes

4.5.1 Document analysis. Glaser and Strauss (1967) suggest that document analysis is often underused as researchers may be concerned over the verification of data or have little if any confidence in data that they have not generated. The authenticity and validity of the documents used in this study can be verified as they originate from international, national and institutional policy documents thereby establishing faith in the data. Documents in this study refer to any written information drawn up prior to the study that influences the structure and implementation of the curriculum. As the purpose was to understand the role and relevance of mathematics in the engineering curriculum, documents included the Washington Accord, ECSA Standards and Procedures System, the CoAES handbook (2012), the module schedule and curriculum documents containing information about the role of mathematics in engineering at the SAHEI as well as what mathematics was seen to be relevant to the engineering context. I analysed these documents to ascertain how they projected the role of mathematics and to what extent they influenced the recontextualisation of mathematics from the academic discipline to the ME module.

4.5.2 Observation. The focus of the second research question was to determine how teaching and learning are approached in the ME module, making the teaching and learning context the source of data. The structure of the module in terms of classification and framing and the teaching style are represented by the interaction between lecturers and students. Observations were used because they offer the opportunity to gain first hand data on the phenomenon under appraisal (Merriam, 1988). The key data source was the teaching and learning context because the focus is on how teaching and learning is approached and the dominant views of teaching and learning that arise in practice. Kuhs and Ball (1986) assert that individual’s beliefs about what constitutes effective teaching and their theories of how students learn influence teaching and learning. Teachers’ views can be determined through identifying characteristics that define a teaching approach thereby necessitating the development of a set of defining characteristics for each teaching approach that can be used as a basis for identifying and justifying the categorization of teaching approach that is used during observation (Kuhs & Ball, 1986). This justifies the use of classroom observations to generate evidence of implicit understandings of the theories in practice (Maxwell, 2005).

Drawing from the theoretical framework discussed in Chapter Two, the identifying characteristics of absolutist, formalist, instrumentalist and fallibilist approaches to teaching and learning were used to construct the observation schedule used to record evidence of teaching styles. For example to identify whether the teacher has a leaning towards teaching instrumentally, I looked for indications of the teacher acting as an authority, encouraging students to take down notes, teaching rules without explanation, demonstrating procedures that students must use and encouraging students to memorise and practice procedures and computation. In the observation schedule one of these indicators was included as: Demonstrates procedures that students must use. On the observation schedule I indicated the number of occurrences of the lecturer demonstrating procedures for each lecture that I observed.

Notes were written up as a narrative as reminders since "notes that make sense to you as you jot them down may not when you come back to them … later" (Flick, 2007, p. 25) and thus facilitated my task as the researcher when clarifying and confirming notes. I noted the times on the audio when statements confirming a view of teaching or learning were made by the lecturer. This assisted me to locate and insert appropriate quotes from the transcript where necessary. The schedule of lecture observations is attached in Appendix D. A rating scale was included in the observation schedule to record the frequency of occurrences of observed behavior as indicated on the schedule. Classroom observation can be conducted in two different ways that can qualify as quantitative or qualitative. As the approach to this study is mixed methods, I chose to approach data collection from both an inductive and a deductive approach by pre-selecting the categories that will count as evidence but also allowing for the emergence of themes that were not initially anticipated. The data from the observation of lectures are presented as three case studies. Figure 4.1, illustrates the observation schedule that was used to collect information in lectures and tutorials in the ME module.

Lecturer: ______ Observation lesson: ______ Date: _____ Audio: _____

1.Never (0 times)	2.Sometimes (2 times)	3. Many (four times)	4. Consistently (more than 4 times)

Makes an effort to build students understanding through:

1. Encourages students to question

√			

Figure 4.1 Illustration of observation schedule for the ME module in 2012

To facilitate the collation and analysis of the data, I audio recorded the lecture that I observed and documented the audio recording number so that I could later transcribe the information and link it to the date and lecturer. My reflections on the lecture, lecturer and students' behavior were documented as field notes where it seemed that it would enrich the data. For example, in the section on composition of functions, when students queried whether the composition could be calculated from the outside in, Dr A responded that it could not. I noted in my journal that the question provided the opportunity for students to develop the understanding of why that would not work in all situations and saw that as a missed opportunity for students to develop conceptual understanding and to explicate evaluative criteria. This additional information could serve as evidence to support the claim that explanatory feedback was seldom provided and therefore I documented it in my journal.

The data was collected as follows: A tick in the first column indicates that the lecturer did not pose questions to students in that lesson. In addition, if questions were asked of students, I recorded the number of questions that were posed to students in that particular lecture so that I could show exhaustive evidence that would determine the extent of the framing of that specific indicator. Attempts were made to collect sufficient data that would enable me to show confidence in the data and to present the "range of their presences and absences in the data" to be able to make "robust claims about pedagogy" (Ensor & Hoadley, 2004, p. 83). In analyzing the data, I looked to do what Ensor and Hoadley refer to as 'exhausting the data set' which to my understanding meant two different processes for inductive and deductive data. For the data collected using the deductive approach, the data collected in the sampling frame had to be representative of classroom life. In the deductive approach exhausting the data set occurs during data collection whereas for the inductive approach, this occurs during data analysis (Ensor & Hoadley, 2004).

Four tutorials supervised by each of the 3 lecturers were used in the analysis of the data. The data creates a picture of how teaching and learning was approached in tutorials.

4.5.3 Questionnaire. To determine internal and external classification of the ME module, I ascertained the classification between the ME module and other engineering modules by examining the interdisciplinary, intradisciplinary and interdiscursive relations. For example, to determine the extent of interdisciplinary relations, the student questionnaire framed specific questions to determine the interrelation between the ME and other modules for which first year students were registered in the engineering curriculum (Figure 4.2). This included the question:

20. Was the content covered in the Math 131 module useful in other modules that you have done?

____

If so state module and content:

Module	Module section	Mathematics content

Figure 4.2 Illustration ofstudent questionnaire item

Interviews with lecturers, observations and the textbook were analysed to ascertain the degree of classification of the ME module content. Questions from the tutorials (textbook) and additional tutorial materials (handouts) were analysed to establish the degree of classification of the module. That is, I looked for evidence of the mention or use of examples from other subjects. For example, the lecturer questionnaire asked: “What is the connection between this module and other modules in the engineering curriculum” and “How does this topic fit in with other topics or sections in this module”?

I employed the assistance of an undergraduate engineering student (specifically not a tutor or SI leader in the ME module) to help me administer the questionnaire. Questionnaires were administered to students during lectures and tutorials in the thirteenth week of the semester. Once the questionnaires were collected, a count of the responses indicated that two hundred and ninety two students participated in the questionnaire. Even though students attached their names and student numbers to the questionnaires, I allocated each questionnaire a three-digit number, say 001 and the codes and questionnaire responses recorded onto a spreadsheet, using Microsoft Excel. Student responses were captured with columns representing questions and rows, the responses of the individual students. Hence each row contained a student’s response for all of the questions. A code book was created to record the codes used for each item on the questionnaire and stipulate what it measured.

Qualitative responses were coded to reduce the data. Written responses to the qualitative questions were coded according to positive or negative in instances where the actual descriptions did not add value to the interpretation and in some cases student's responses were grouped according to similar meanings to form categories. For example, responses to the question asking students to substantiate their responses to the question: Was there good alignment between lectures, tutorials and assessments?, were grouped together as negative factors and coded as such in the code book. Likert-type questions were recorded according to codes. For example, the codes (0, 1, 2, 3, 4, 5 and 9) were used in cases where five responses were catered for. Similarly for items that catered for a binary response, zero and one were used to indicate responses of 'no' or 'yes' respectively. The digit '9' was used uniformly with the qualitative and quantitative data to indicate 'no response'. Written explanations and descriptions were entered verbatim onto the excel spreadsheet. I wanted the data to be recorded in the way it was written and therefore spelling and grammatical errors were recorded as they appeared in the responses on the questionnaire. Once this was completed, the responses to the qualitative (semi-structured and open-ended) and quantitative questions were moved to separate sheets in order to facilitate the analysis. The quantitative data recorded on the first sheet of the spreadsheet were analysed quantitatively, whilst the qualitative data were analysed qualitatively. The themes arising out of the questionnaire were used in the write up of the study.

As the data was entered, the nuances in the data began to emerge. I noted key words relating to the emerging themes that I documented and later used to filter data in order to identify segments of student responses. What I realized upon entering the response of the question on alignment: *Do you think there was good alignment between lectures, tutorials and assessments?* into excel is that students had interpreted this question in two ways. Firstly, some students interpreted the question in the light that I had intended, which was to comment on whether they felt that lectures supported tutorials and assessments, whether tutorials supported assessments and whether assessments were a good indication of what students had been exposed to in lectures, tutorials and assessments. This was evident in responses such as: "yes the test questions came from the tut questions" (Student questionnaire, Student 831, 2012) and "yes I was well-prepared for all assessments" (Student questionnaire, Student 833, 2012). However some students interpreted it as though the question was making reference to the sequence of topics in lectures, tutorials and assessments as was exemplified in the following excerpts: "They always in what our lecturer taught us and we always get them after doing those topics in our lecture room" (Student questionnaire, Student 846, 2012) and "things you do during lectures during a specific period of time were also done in tutorials and assessments" (Student questionnaire, student 777, 2012). I believe that both were valid and important interpretations of the question and as such accepted and recorded responses of both interpretations. Doing this provided me with information that was used to make assertions about teaching and learning.

4.5.4 Interview. The interpretations of Bassey (1999), Gibbs (2007), Kvale (1996, 2007), Kvale & Flick (2008), Merriam (1988) and Silverman (2009) were used in the design of this study. Kvale and Flick (2008) characterize the interview as structured conversations that are guided by a purpose which is determined and controlled by the researcher. Interviews are viewed as a "moral enterprise" which influence the process of data generation, collection and the interpretation and reporting thereof (Kvale & Flick, 2008). This is significant in that the interaction between interviewer and interviewee influences how the reader understands the "human condition". Interviews provide the opportunity for the researcher to understand a situation from the perspective of the interviewee and to determine the meaning of their experiences (Kvale, 1996) in an efficient and valid way (Maxwell, 2005). The purpose of the interview then is to obtain information that has been thoroughly tested through listening and questioning. It can enhance the information gained from other methods of data collection, in this case, observation of lecturers and tutorials (Maxwell, 2005). Kvale (1996) acknowledges that while the interview does not result in objective information, it does provide access to meaningful information. Interviews with lecturers were thus the most appropriate way for me to illicit an understanding of how teaching and learning is approached in the ME module as well as what motivates academics in their approach.

The interview was designed to initiate a rational dialogue between interviewee and interviewer with the aim of "analytically clarifying conceptions of the phenomena investigated" (Kvale, 1996, p. 127). I framed the interview questions in a way that would generate the responses necessary to answer the research questions. For example, to identify lecturers' perceptions of how students should learn mathematics, the question: *How should students go about learning mathematics in this module?* was included. The interview questions were semi-structured with probing questions and hints added to my list of interview questions that would guide the interview process (Patton, 2002) and remind me to probe and clarify responses and pursue other themes that emerged in the process. As Merriam (1988) suggests, selecting the interviewees depends on what the researcher wants to determine and from whom that information is best gained. In this study I sought to determine in depth information about teaching and learning mathematics to future engineers thus identifying the three lecturers lecturing in the ME module, the HoS (Mathematics), 14 successful students and 6 tutors as interviewees. Interview schedules were developed for each set of interviews.

Each interview with the lecturers lasted approximately an hour. With the permission of the participants, interviews were audio-recorded. Doing that allowed me to concentrate on the interview at hand, clarify questions, probe student responses, and develop a rapport with the interviewees. I had to acknowledge and account for the fact that during the actual interview process, participants could encounter stress and undergo changes as a result of the interaction with the interviewer. To reduce the stress levels, copies of the interview questions were given to students at the start of their interview and they were given time to read through the questions and respond once they were ready. To extract the data from the interviews, I transcribed the same from the audio recording, a process that allowed me to become familiar with and understand the nuances in the data as they emerged. As I transcribed the data, I entered it into a spreadsheet, facilitating the filtering of data that would assist me in comparing data and identifying patterns. For example, I was able to collate all the responses to the first question in the interview and further filter them according to factors pertaining to lectures, tutorials, assessments and on-line assistance. Once the transcription was complete, I read through the data again deepening my understanding of it. From the spreadsheet I was then able to draw the dominant perceptions and used appropriate transcriptions to support my findings and any claims that I made. This was done in collaboration with themes highlighted in the literature. In this section, all quotes made by lecturers are italicized and pseudonyms used to distinguish between respondents while protecting their identities. The quotes are taken directly from the interview transcripts. Any changes made to enhance the understanding are indicated within ‘square brackets’.

4.5.5 Evidence collected. The evidence that was collected was drawn from documents, observation, interviews and questionnaires are tabulated in Table 4.2.

Table 4.2

Table of Data Collection Methods and Data Sources

Data collection method	Data source
Documents	SAHEI College of Agriculture, Engineering & Science Handbook, 2012 ME module outline SAHEI mission statement ECSA requirements and the Washington Accord Curriculum documents, tutorial and additional tutorial exercises Lecturer notes Mock tests, mock examinations, tests and final module examination
Observation	Recorded information according to the observation schedule (no of times a specific indicator was observed) Audio-tape to review the data and capture quotes Field notes with examples to exemplify the presence or absence of evident
Interviews	All interviews were conducted independently (1:1) and were audio taped and transcribed The Dean was interviewed to determine the role of mathematics in engineering, influences on the ME curriculum and approaches to teaching and learning Academic staff lecturing in the module to determine how they approached teaching and learning and why, also reasons for students success and failure, including enabling and disabling factors in students learning Students: to determine enabling and disabling factors in their success in the ME module, that is did they acquire the relevant recognition and realization rules.
Questionnaires	Academic staff: to establish the role and nature of mathematical knowledge. Data was used to provide a detailed picture of teaching and learning approach. Students: identify themes with regard to enabling and disabling factors To triangulate the data and to determine the nature of ME content.
Field Notes	I kept a journal that I recorded notes in during observation and interviews. The notes included comments on what the lecturer said, or a question the student asked, or a reminder to me to probe into certain aspects of behavior during interviews, or to record the reference point on the audio when the lecturer said something that would exemplify a point/ claim. I also recorded my own thoughts about questions that I should include during the interviews.

4.6 Languages of Description

The paradigmatic orientation to this study is that of pragmatism, a stance that embraces not only a mixed methods approach to data collection, but also one that encourages the use of methods that are most appropriate for the collection of data that best answer the research questions. Moore (2013) asserts that Bernstein's theories were in keeping with the mixed methods approach to research, as Bernstein's theories supported "meta-dialogue, mixed theory and mixed method and also, in teaching, mixed pedagogies: that we begin with a *problem* and then mobilise our resources, theoretical and methodological around the problem. The problem comes before the approach" (p.4). In this study, the problematic is teaching and learning in the ME module and the methodology and methods selected centre on generating data that will answer the research questions. To examine the structure of the pedagogic device, I used the analytic framework provided by Bernstein (1996, 2000) which encapsulates the classification and framing of pedagogic practice.

Bernstein provided a language of description which,

> constructs what is to count as an empirical referent, how such referents relate to each other to produce a specific text and translate these referential relations into theoretical objects or potential theoretical objects. In other words the external language of description (L2) is the means by which the internal language (L1) is activated as a reading device or vice versa. (2000, p. 132)

Both the theoretical and empirical are considered to provide the internal and external languages of description which work dialectically to guide the analysis. The external language of description is developed by drawing on the internal language of description and consists of propositions and models (Morais & Neves, 2001) making it more applicable to analyzing and interpreting empirical data as well as in initiating the internal language (Morais & Neves, 2001; Ensor & Hoadley, 2004; Parker, 2008). To avoid circularity, the theory constructs "at the *level of description* only that which lives within its own confines" which will also ensure the integrity of the evidence (Bernstein, 2000, p. 91). The analytical framework is drawn from the work of many authors who have used Bernstein's work to inform their own research (Ensor & Hoadley, 2004; Hoadley, 2006; Morais & Neves, 2001). Bernstein's (2000) languages of description were a good fit in terms of facilitating the collection of data that provided insight into the role of mathematics and the structure of the ME module. The dialectical interaction between Bernstein's theoretical models, the languages of description and analysis of empirical data brings out a more rigorous and deeper understanding of the social relations that constitute pedagogic practice evident in the ME module in the SAHEI.

To be able to adequately conceptualise and identify the constructs of classification and framing, an external language of description was developed to categorise what is to count as evidence of classification and framing as "every investigation requires the construction of an external language of description that consists of empirical categories that can unambiguously be translated into the conceptual categories of the internal language" (Moore & Muller, 2002, p. 634). Drawing on Hoadley (2006) and Neves and Morais (2005), I identified the indicators that would allow me to recognize empirical instances of classification and framing. For example, to determine the classification of content between disciplines, I examined the discursive relations between the ME module and other modules in the first year engineering curriculum (Physics, Chemistry, Applied Mathematics). On the one extreme end of the scale, the code C++ was used to indicate a very strong classification and describes the boundaries between mathematics and other subjects as being very strong which means that there is little or no indication of where content in the ME module fits in with other modules. On the other extreme end of the scale, a C-- was used to indicate very weak classification and describes the boundaries between mathematics and other subjects as being very weak which means that the relations between ME content and content in other modules are often shown.

4.7 Data Analysis

Data analysis is the process of making sense of the data in a way that facilitates transcending the mere description of data to avoid misinterpretation of and trivialising the findings (Goetz & LeCompte, 1984). The theoretical framework used in the analysis of the data was the result of the review of the literature, comparative data coding, and quantitative frequency counts. The meticulous analysis of data is necessary, as while the raw data presents an interesting sketch, it does not illuminate the phenomena under scrutiny sufficiently to enhance the readers understanding of it and the way the contributors to the study perceive it.

Systematic analysis of data serves to highlight the existing phenomena and illuminate their situation (Basit, 2003).

There are various methods that can be used to look at data and how the data can be analysed. In keeping with Mason (2002), Gibbs (2007) suggests that the focus of qualitative analysis is to first provide a ‘thick’ description that illustrates the richness of the data and highlights what people intend to do and how they intend to do it. It is this ‘thick’ description that enables the researcher to venture an explanation or interpretation of the data. Qualitative analysis uses both inductive and deductive logics of explanation to find patterns and provide explanations. Gibbs (2007) claims that “the idea of analysis implies some kind of transformation. You start with some (often voluminous) collection of qualitative data and then you process it, through analytic procedures, with a clear, understandable, insightful, trustworthy and even original analysis” (p.1) and that “qualitative analysis usually seeks to enhance the data” (p. 4).

The styling conventions used in coding and in the write-up of the findings follow those mentioned by Gibbs (2007). All interviewee names were represented by pseudonyms which were specifically allocated to them and recorded in the code book. This was followed by a colon, tab and then their response following on the same line. Student questionnaires were coded with numbers which were recorded on each questionnaire sheet. This allowed me to identify which questionnaire the response came from should it be necessary to revisit that response. I ensured that the text did not reveal blatant clues that could be used to identify a participant. Gibbs (2007) suggests that tidying up the interview transcript can be beneficial in terms of facilitating reading and analysis and is acceptable if the factual content of the data is more crucial to the research than the expression and language used. In this study, I chose to remove repeated use of expressions like “er”, “ehm”, and the like as it did not alter the meaning, expression or language of the interviewee. Incorrect spelling of words in the questionnaire or use of words incorrectly, grammatical errors and the like were not changed. Whenever I encountered a display of a definite expression, I noted this in my observation and interview notes as “people hesitate, they stress words and syllables they overlap their speech with others” (Gibbs, 2007, p. 14) and this enhances the data.

4.7.1 Transcription of student interviews. I had the choice of doing the transcription of the data myself or enlisting the assistance of a paid professional to do it. I was advised by my colleagues to transcribe the data myself as it would enable me to get a ‘feel’ for the data and identify the nuances and salient points it contained. I found that in accordance with Gibbs (2007), listening to the audio-tapes, reading, transcribing and re-reading provided the opportunity for me to familiarize myself with the data, and to begin the data analysis. The data were then organized into coherent categories and coded. Throughout this process I revisited the key questions that the analysis should answer, organized the data by questions and explored the connections and relationships between questions and data. Following the advice of Gibbs (2007), I added line numbers to the transcriptions for the purpose of cross-referencing and used margins on the right to annotate ideas and coding. Double line spacing was used to allow space for underlining, and comments. A similar process was followed for observation data. Ultimately, the data that were collected had to be used to answer the research questions. A summary of classification and framing in the ME module is presented in Table 4.4.

Table 4.4

Summary of Classification and Framing (Table adapted from Hoadley, 2006).

C/ F	Categories	Descriptor	
Framing	**Discursive rules**	Extent to which teacher controls selection of content	**F+/ -**
		Extent to which teacher controls sequencing of content	**F+/ -**
		Extent to which teacher controls pacing of content	**F+/ -**
		Extent to which teacher makes explicit the rules for evaluation of students’ Performances	**F+/ -**
	Hierarchical rules	Extent to which teacher makes formal or informal the social relations between teacher and students	**F+/ -**
		Extent to which the teacher controls interactions between students	**F+/ -**
Classification	**Relations between Discourses**	Inter-disciplinary (strength of boundary between mathematics and other subject areas)	**C+/ -**
		Inter-discursive (strength of boundary between school mathematics and everyday knowledge)	**C+/ -**
		Intra-discursive (strength of boundary between different topics within mathematics)	**C+/-**
	Relations between Spaces	Teacher – learner (strength of demarcation between spaces used by teachers and students)	**C+/ -**
		Space for learning (strength of demarcation between space used for learning)	**C+/ -**
	Relations between Agents	Teacher – learner (strength of demarcation of pedagogic identities)	**C+/ -**

4.7.2 Classification. As mentioned earlier in Chapter Two, classification represents the extent of insulation between categories and agents. Drawing on the research conducted by Hoadley (2006), I found that the scales she used to determine classification and framing were suitable for use in the context of this study. I drew on the internal and external language of description used in her study to develop both the internal and external language of description to answer my research questions. In my study I sought to determine the classification of the ME module content on three levels: interdisciplinary, intradisciplinary and interdiscursive levels. For example, the internal language of description used by Hoadley (2006) describes the relations between discourses in terms of interdisciplinary (strength of boundary between mathematics and other subjects), interdiscursive (strength of boundary between school mathematics and everyday knowledge) and intradiscursive (strength of boundary between different topics within mathematics). The external language of description was developed from the internal language of description as used in Bertram (2008) (see Table 4.5). Using the internal language of description (interdisciplinary classification) I looked for descriptors that would enable me to identify behavior associated with inter disciplinary classification. For example, the classification could be very strong, strong, weak or very weak. The distinction between these descriptors was specified as C(++) indicating very strong classification and describing the boundaries between mathematics and other subjects as being very strong (never indicates where the ME module fits in with other modules) or (C+), indicating strong classification and describing the boundaries between mathematics and other subjects as being strong (seldom mentions how ME fits in with other modules) or (C-) indicating weak classification and describing the boundaries between mathematics and other subjects as being weak (sometimes shows relations between ME and other subjects) or finally as (C-) indicating very weak classification and describing the boundaries between mathematics and other subjects as being very weak (often shows relations between ME content and other modules). These descriptors constituted the external language of description as they enabled me to observe and collect empirical evidence that assisted me identifying the extent of classification of the module.

To do this I looked for evidence of integration between different topics or sections within the ME module to determine intra disciplinary relations, between modules of the first year engineering curriculum for inter disciplinary relations and between academic and everyday knowledge to ascertain the degree of inter discursive classification. Inter-discursive relations are those relations that exist between vertical knowledge and horizontal knowledge.

Here the link between theoretical and empirical knowledge is elucidated to determine the extent to which everyday knowledge is incorporated into the ME module. At the intradiscursive level the focus is on the relations between topics within a particular discipline or module (Hoadley, 2006). As mentioned earlier, strong classification is evident when there is a distinct boundary between two categories while weak classification is exhibited when there is some degree of interrelation between the contents of a particular discipline. For example, where else in the ME module is the concept of definite integrals relevant and applicable? Bernstein's concept of classification is central to explaining the structure and organization of the content through analyzing the strength of boundaries between the different topics which constitute the content (Sadovnik, 1991). Integration of content within a module enables the development of broad concepts that bring about understanding. A clear distinction between contents is reflective of strong intradiscursive classification which would be demonstrated when there is no interrelation between contents resulting in the collection of facts without an explanation of how they relate to each other. Furthermore, the spaces between academics and students (in lectures and tutorials) will be examined. Clearly-defined values of classification will be used to characterize the gradations between weak, strong and very strong classifications that are explicated further in terms of teacher and students spaces.

Weak classification of the student-student relation is characterized by boundaries between diverse groups of students which are not distinct (that is they are blurred). Similarly weak classification between social spaces is evident when students share resources and spaces. This contrasts with strong classification where relations between students are distinct (hierarchies exist between students) and between spaces and resources allocated to teachers and students. Classification thus has implications for teaching and learning. A five-point rating scale was used to distinguish between the degrees of strength of classification (C+/ C-) and framing (F+/ F-), with C0 and F0 indicating insufficient evidence to assess this criteria.

The classification categories ranged from 'never' up to 'often' and were used to identify indicators that showed evidence of degree of classification are tabulated in Table 4.5 and 4.6.

Table 4.5

Summary of Descriptors of Classification (adapted from Bertram, 2008)

Inter disciplinary classification

In this category I looked for discursive relations between the ME module and other modules in the first year engineering curriculum (Physics, Chemistry, Applied Mathematics)

C++Indicates very strong classification and describes the boundaries between mathematics and other subjects as being very strong (never indicates of where ME fits in with other modules)

C+ Indicates strong classification and describes the boundaries between mathematics and other subjects as being strong (seldom mentions how ME fits in with other modules)

C- Indicates weak classification and describes the boundaries between mathematics and other subjects as being weak (sometimes shows relations between ME and other subjects)

C- Indicates very weak classification and describes the boundaries between mathematics and other subjects as being very weak (often shows relations between ME content and other modules)

Intra disciplinary classification

In this category I looked for discursive relations between the various topics and sections within the module

C++ Indicates very strong classification and describes the boundaries between different topics sections within the module (never indicates where a topic/ section fits in with other sections)

C+ Indicates strong classification and describes the boundaries between different topics sections within the module (seldom mentions the relationship between different topics/ sections in the ME module)

C- Indicates weak classification and describes the boundaries between different topics sections within the module (sometimes mentions the relationship between different topics sections in the ME module)

C-- Indicates very weak classification and describes the boundaries between different topics/ sections within the module (often indicates where a topic/ section fits in with other sections)

Inter discursive classification

In this category I looked for discursive relations between the ME module and everyday knowledge

C++ Indicates very strong classification and describes the boundaries between mathematics and everyday knowledge as being very strong (never indicates where ME fits in with everyday knowledge)

C+ Indicates strong classification and describes the boundaries between mathematics and everyday knowledge as being strong (seldom mentions how ME fits in with everyday knowledge)

C- Indicates weak classification and describes the boundaries mathematics and everyday knowledge as being weak (sometimes mentions how ME fits in with everyday knowledge)

C-- Indicates very weak classification and describes the boundaries between mathematics and other subjects as being very weak (often shows relations between ME content and other modules

Often the distinction between calibrations on a scale may not be viewed similarly by all as different people may regard the degree of difference between for example, 'seldom' and

Table 4.6

Summary of Descriptors of Classification of Spaces, Learning and Agents (Adapted from Bertram, 2008)

Relations between spaces **In this category I looked for relations between spaces used by teacher and learners** (strength of demarcation between spaces used by teachers and students)
C++ Indicates very strong classification and describes the strength of demarcation between spaces used by teachers and students) (teachers never transcend demarcation between space used for learning) C+ Indicates strong classification and describes the strength of demarcation between spaces used by teachers and students) (teachers seldom transcend demarcation between space used for learning) C- Indicates weak classification and describes the strength of demarcation between spaces used by teachers and students) (teachers sometimes transcend demarcation between space used for learning) C- Indicates very weak classification and describes strength of demarcation between spaces used by teachers and students) teachers often transcend demarcation between space used for learning)
Space for learning **In this category I looked for relations between spaces for learning (strength of demarcation between space used for learning)**
C++ Indicates very strong classification and describes the relations between spaces for learning as being very strong (teachers never transcend demarcation between space used for learning) C+ Indicates strong classification and describes the relations between spaces for learning as being strong (teachers seldom transcend demarcation between space used for learning) C- Indicates weak classification and describes the relations between spaces for learning as being weak (teachers sometimes transcend demarcation between space used for learning) C-- Indicates very weak classification and describes the relations between spaces for learning as being very weak (teachers often transcend demarcation between space used for learning)
Relations between agents (pedagogic identity **In this category I looked for relations between teacher and learner (strength of demarcation of pedagogic identities)**
C++ Indicates very strong classification and describes the relations between teacher and learner being very strong (teacher never indicates) C+ Indicates strong classification and describes the boundaries between relations between teacher and learner as being strong C- indicates weak classification and describes the relations between teacher and learner as being weak C-- Indicates very weak classification and describes the boundaries between relations between teacher and learner as being very weak

'occasionally' to be insignificant. I therefore clarify here that the difference between the four points on the scale are presented in order of increasing occurrence: never, seldom, sometimes and often. Hence the point 'sometimes' indicates a more frequent occurrence of an observed behavior than 'seldom'.

4.7.3 Framing. The concept of framing was used to analyse the relations within the various categories that constitute pedagogy in the module under scrutiny. Framing determines the extent to which the lecturer has control over the learning environment in terms of teaching, learning and assessment. To fully understand the structure of pedagogic practice I examined the extent of framing in two senses. First I analysed the pedagogic practice in terms of the discursive rules constituted by selection, sequencing, pacing and evaluative criteria. Second I analysed it in terms of the hierarchical rules comprising the extent to which the lecturer makes formal or informal the social relations between lecturer and student and extent to which the lecturer controls interactions between students. The internal and external languages of description for framing were developed in a similar way to the development of the internal and external languages of description for classification which has been described previously. To do this I identified the units of analysis that would inform the collection of data. The units under analysis were the lecturers and students involved in the ME module. In this category I looked for lecturer control over selection, sequencing, pacing and evaluative criteria with respect to lectures, tutorials and assessment in the ME module. As with the process used to identify the extent of classification, descriptors were formulated to identify instances of behavior that were used to determine the extent of framing over selection, sequencing, pacing and evaluative criteria.

Strong framing reflects strong control by the teacher over the discursive and hierarchical relations (F++). It also indicates that students do not have a say over the discursive or hierarchical relations. Weak framing reflects that teachers have implicit control but students also have 'apparent' control over the rules (F--).

4.7.4 Evaluation. Bernstein's theories of pedagogy highlight the key role of evaluative criteria in identifying pedagogic practice that best enhances student success in the educational context. The strength of framing over the evaluation criteria is expressed in terms of the standard Bernsteinian notation as used in Hoadley (2006), where F^{++} represents very strong framing and F^{+} represent strong framing. Similarly, F^{--} represents very weak framing and F^-, weak framing. The coding scheme arose out of the interplay between the theory and the data. The initial coding scheme used was matched closely to that in Hoadley (2006). As the data was generated, the coding scheme was modified so that it could respond more effectively to the nuances that were emerging from the data. The result of the process of developing the coding scheme was the ‘external language of description’ (Bernstein, 2000) which clarified the indicators (theoretical constructs) that were used to measure the degree of framing of the evaluative criteria. Drawing from the data, a sample of observed lectures was coded in accordance with the coding scheme. The different dimensions of pedagogy (from Bernstein’s theories) that were being analysed were associated with specific indicators and included in the coding scheme. The lectures that were observed were coded according to these indicators.

4.8 Analysis of the Final Examination Questions

Bloom’s Revised Taxonomy was used to determine the cognitive demand of the questions in the final examination. For each category of knowledge, I looked for indicators that allowed me to identify what counts as evidence for each level according to the structure of the revised taxonomy. These were then recorded in the taxonomy table. The mock and final examination papers were analysed to determine the cognitive demand of the problems that students were given. This enabled me to determine the level of cognitive development the teaching and learning aimed to achieve thereby addressing the question of quality of the examination. Furthermore, the alignment between lectures, tutorials and assessments was investigated by comparing questions from tutorials and assessments.

4.9 Issues of Ethics, Validity and Reliability

Issues of ethics, validity and reliability are critical in a study (Guba & Lincoln, 1985). The next section describes the methods that were used to ensure that the study was conducted in an ethical manner and that valid and reliable data were generated. The Turnitin report verifies that the thesis does not contain information from other sources without being acknowledged (Appendix A).

4.9.1 Ethical issues. Kvale and Flick (2008) identified seven research stages and fore grounded the ethical issues that they believe need to be considered at each of these research stages. In thematising and designing the study, the researcher should ensure that the purpose of the study addresses and transcends the scientific value of the knowledge to the value that it can add in improving the human context under scrutiny. During the design phase of this study, the following issues concerned with ethics were thus considered: ethical clearance by the institution in which the study was being conducted, informed consent by participants in the study (students, academics, tutors), ensuring participant confidentiality and anonymity and giving significance to the consequence of participation to the participant. Gatekeeper's permission was granted by the registrar of the university (see Appendix B). A request for ethical clearance outlining the purpose, methodology, methods to be used in the study and the steps that would be taken to ensure that ethical procedures were followed was made. Ethical clearance was granted by the Research Office at the SAHEI in September 2011; Protocol reference number HSS/0935/011D (see Appendix B).

Guba & Lincoln (2005) debate the need for informed consent emphasizing that the shift toward qualitative research that is more mutual, egalitarian and obliging, renders informed consent redundant in research that is regarded as low risk. Be that as it may, Parker (2005) offers a different perspective on the issue of confidentiality asserting that anonymity serves to silence the participants' voice, thereby protecting the researcher. Informed consent was sought from participants in the study who were informed of their right to participate as well as to withdraw at any stage of the study, the consequences of their participation and how the data would be used. In considering the ethics around the study, I ensured every step of the way that participants could not be harmed by any aspect of the data collection, analysis and write-up and that their anonymity was maintained. To maintain the confidentiality that was promised to participants the following naming mechanisms have been adopted and are used throughout the thesis: (1) academics lecturing in the module have been allocated a letter of the alphabet, hence Dr A lectures to group A, Dr B to group B and Dr C to group C; (2) the Head of School of Mathematics is referred to as the HoS; (3) students who were interviewed have been allocated letters of the alphabet to distinguish between the various respondents hence they are referred to as Student A ; (4) students whose responses from the open-ended questions on the questionnaire have been used are referred to as Student 001; (5) tutors who were interviewed are also allocated letters of the alphabet and referred to as Tutor A, Tutor B and so forth and the name of the module under scrutiny has been changed to the Mathematics for Engineers module or the ME module. The name of the institution has been changed to the South African Higher Education Institution and is referred throughout as the SAHEI. In the interview transcript, references to academic or institution's name and other identifying characteristics have been changed to comply with the promise of confidentiality and anonymity. To ensure that students were aware of the ethical issues and that their rights would be protected, the first page of the student questionnaire consisted of the letter of consent. In order to maximize the anonymity of the institution and participants in this study all references to the geographical location of the SAHEI have been removed and the three lecturers involved in the study have all been represented as male.

The data collection commenced at the beginning of the semester and continued until after final module marks for the final examination were released. Throughout this study, the data collection process, handling and analysis of data were conducted in accordance with ethical guidelines.

4.9.2 Validity and reliability. Whilst previously research was said to be valid if it measured what it purported to, current theory considers the principles of validity in quantitative, qualitative and mixed method in different ways (Winter, 2000). The notion of validity being absolute is idealistic, says Gronlund, who leans towards the notion of degrees of validity, and claims researchers should strive to maximise validity and minimise invalidity. In mixed methods research Johnson & Onwuegbuzie (2006) refer to validity as legitimation. They identify nine types of legitimation in mixed methods research which they claim are sufficient to overcome problems of representation, legitimation and integration associated with mixed methods research.

Validity in quantitative research is expected to be true to its positivist principles and are replicable, predictable and context-free (Cohen, Manion & Morrison, 2011). Principles of validity in qualitative research differ from those in quantitative research in many ways (Bogdan & Biklen, 1992) including that data is often unique, rich and descriptive and the researcher who is often the key research instrument. To minimize the threat to validity in this research, I aligned with King, Morris and Fitz-Gibbon's (1987) suggestions in selecting an appropriate time scale and ensuring that there were adequate resources for the research to be undertaken. The ME module was bound by time in the first semester and since I was the key research instrument and would be conducting the research, minimal resources were required.

In keeping with King *et al.*'s (1987) stance, I ensured that I used appropriate methods for data collection and designed appropriate instruments for collecting the data that was necessary to answer the research questions. For example, to develop an understanding of how teaching and learning is approached I chose the method of observation. In order to direct my gaze on that under scrutiny, teaching and learning, I developed a language of description using Bernstein's concepts of classification and framing which enabled me to identify indicators that were associated with specific behaviours (discussed earlier in this chapter).

Validity and reliability in interviews: A validity concern is whether the research questions ask what they purport to and whether the instruments measure what they should (Cohen *et al*., 2011. Bias is one cause of invalidity and hence minimizing bias is one way of validating an interview. Cohen *et al*. (2011) list as some of the sources of bias the interviewer, the characteristics of the respondent and the meaning of the questions. In keeping with Silverman's (2003) suggestion I piloted the interview schedule and interview questions with students and my colleagues not involved in doing the first year mathematics module in engineering to help reduce the bias in the interviews. This was done to ensure that the meanings of the questions were not ambiguous and that the questions asked and elicited what they meant to. Piloting also gave me some insight into respondent characteristics and helped me to refine my skills as an interviewer.

Research in general poses a threat to those who participate as the fear of repercussions is always rife and this could affect the validity of their responses. In this research the threat was minimized as participants were assured of anonymity. I as the interviewer in this study had minimal if any influence or power over the respondents whether staff or students, as I worked in a different unit of the university. To control for reliability the interviews were highly structured. The interview questions were prepared beforehand and once in the interview room interviewees were given a copy of the interview questions and some time to look through just before the interview commenced. This gave them the opportunity to think about their responses before the actual interview started. It was important that the questions were asked consistently since changes in wording, context and emphasis undermine reliability, because it ceases to be the same question for each respondent" (Cohen *et al*., 2011, p. 204).

Following Kvale (1996) the interview was well-structured and the process and purpose of the interview were made clear to the interviewees when they were invited and verbally at the beginning of the interview session. Participants were given sufficient time to respond to the interview questions. As I conducted the interview, I ensured that I listened carefully and attempted to be empathetic but also delicately kept the interview on track. Once all the questions and responses were completed participants were given an opportunity to ask questions or to say anything they felt would add value to the study. This was recorded at the conclusion of each interview. As suggested in Cohen *et al*., (2011) I clarified and confirmed participants' responses and made changes and notes to confirm meanings.

The issue of validity in observation research concerns the construct under investigation and the indicator that captures it. For example in observing instances of framing over evaluative criteria I had to specify the indicator that would identify the construct evaluative criteria and furthermore the extent to which the evaluative criteria, if present, were so. The indicator was any mathematical problem that was associated with the assessments or the examination and the extent to which it occurred in a lesson was measured as did not occur at all, occurred sometimes (1 or 2 times), occurred several times (3 or 4 times), occurred all the time (5 times and more). In this way, I was able to link the internal and external languages of description (Bernstein, 2000). Using these indicators, I knew exactly what to look for and how to measure the extent of its presence

To ensure the reliability of my observation data I used the same observation schedule and observed lectures until I 'exhausted the data set'. Since the lecture groups comprised large student numbers (between 150 and 200 students) and venues were tiered my presence was barely noticed and I believe thus did not affect students' behaviour during my observation. Furthermore my observation was always of the lectures, tutorials and lecturer so my actions were more in keeping of that of a student rather than a researcher and were not necessarily out of place in lectures or tutorials. During lectures as I recorded data on the prepared observation schedule, I audio-taped lectures and whenever interesting or salient points pertinent to the study were made by lecturers or students, I noted the audiotape number and time and made a note of the point so that I could refer to it later. In these ways I attempted to maximize the reliability and validity of data collected during observation.

The validity and reliability of a case study, as in the case of other research approaches, is no less than any other approach and rests as much with the rigour adopted in conceptualising the research design as it is in the collection, analysis and interpretation of data (Merriam, 1988). Lather (1991) asserts that "if illuminating and resonant theory grounded in trustworthy data is desired, we must formulate self-corrective techniques that check the credibility of data and minimise the distorting effect of personal bias upon the logic of evidence" (1991, p. 66). Invalidity can be reduced in many ways. One of these is to minimize reactivity effects as people have a tendency to react differently under interview conditions since the way we study people tends to distort their lives (Lave & Kvale, 1995). To enhance the opportunity of obtaining credible, unbiased data, I met with the academics lecturing in the module as I wanted to develop a relationship and environment of trust which would allay fear and distrust and encourage participation, cooperation and honesty since honest and open responses were crucial to establishing trustworthy and reliable data. To ensure that the maximum number of students targeted for the student interviews did indeed respond, I contacted them telephonically as well as by e-mail, explained the purpose of the research, the reason for interviewing them and assured them that their responses were valuable to the study.

Reliability of data in qualitative research is associated with terms such as consistency, dependability, trustworthiness and transferability (Lincoln & Guba, 1985). Silverman (1993) suggests that highly structured interviews with the same format, that is the same sequence of words and questions serve as a control for reliability and can minimize the effect of bias. To ensure that the respondents understood the questions in the same way, I first discussed the questions with my colleague and we discussed the different ways in which the questions could be interpreted. In addition, I piloted the interview questions with groups of students early in 2012. Questions that seemed ambiguous were then rephrased to remove the ambiguity. Oppenheim (1992) suggests that bias is also encountered when interviewees display poor prompting and bias probing skills. I attempted to allow the respondents to answer as fully as possible before I asked probing questions. Pre-emptive probing questions were phrased ahead of the interview to cater for various responses to avoid asking biased or leading questions. For example, the interview question read: How did you go about or make use of lectures?, the probing question that was to follow was "talk a bit about the preparation you did before each lecture." (probe to illicit how they prepared for each, how they made use of the sessions, and whether it was beneficial to their success). To ensure that I did capture the essence of what interviewees were saying interviews were audio-taped so that I could play and re-play them to ensure that I had correctly captured the responses and expressions.

Issues of validity are central to any study (Guba & Lincoln, 1985). Triangulation of research methods can be used to strengthen a study (Patton, 2002), which also serves to reduce the risk of biased generalizations and conclusions being drawn (Maxwell, 2005). Maxwell, in addition, explains that triangulation provides the opportunity to gain a more in depth understanding of the phenomenon under investigation. Interview, observation and document analysis were used in the study. Observation of lectures and tutorials allowed me to collect evidence of behavior in their natural contexts. Interviews provided the opportunity for participants to justify their actions and to provide access to data that could not be elicited through observation (Maxwell, 2005). Document analysis was used to elicit evidence of policies, requirements of statutory bodies, the ME module and the institution. The various sources of data enabled the collection of data that reduced the risk of bias.

4.10 Conclusion

Chapter Four presented a discussion of the paradigmatic, epistemological, ontological and methodological orientation to the study. The methods of data collection and analysis followed in the research were described as were issues of ethics, validity, trustworthiness and reliability of the data. Chapter Five will present the role of mathematics in engineering as viewed by the literature, the international alliance, statutory bodies and the institution.

Chapter Five
The Role and Relevance of Mathematics in Engineering

The first research question addresses the role of mathematics in engineering. This question is addressed as a literature survey to establish the national and international norms with respect to the role of mathematics in engineering. In this chapter I begin by discussing the relationship between mathematics and engineering and describe the reasons underlying the international concern and significance attributed to the role of mathematics in engineering, a compulsory component of the engineering curricula globally. Following this, the role of mathematics as indicated by external influences (Washington Accord and the Engineering Council of South Africa) and internal influences, the SAHEI CoAES handbook (SAHEI, 2012a), the Head of School and lecturers in the ME module and engineering is also presented. The accreditation requirements of the statutory body for engineers (ECSA) are made clear. Following this is an account of how the SAHEI, more specifically the Schools of Engineering and Mathematics, together with ECSA, have interpreted and responded to these requirements. A comprehensive description of the ME module is provided to show how the institution has taken this forward with special focus on which mathematics is seen to be relevant to engineering in this particular South African higher education institution.

5.1 Relationship Between Mathematics and Engineering

In this section I draw on the literature to discuss the relationship between mathematics and engineering, the value of mathematics to engineers and the consequences of lacking mathematical competence and finally the selection of mathematics to be taught to future engineers.

5.1.1 Reciprocal relationship between mathematics and engineering.

Mathematics and engineering share a reciprocal relationship since mathematics as a discipline can be viewed as a service module to engineering whilst also developing as a discipline due to progress in engineering (AMSI, 2008; Henderson & Broadbridge, 2007). The value of mathematics to engineering is not only seen in its role in developing engineers who are adequately prepared for the mathematical demands of their profession, but also in how engineering as a discipline stimulates new developments in mathematics. Mathematics and engineering as disciplines are enmeshed in a reciprocal relationship with each other (AMSI, 2008; Henderson & Broadbridge, 2007).

5.1.2 Value of mathematics. There is strong agreement in the literature that engineers require a solid mathematical grounding. The literature indicates that mathematics lays a strong foundation for the development of analytical and problem solving skills that engineers are called upon to demonstrate in engineering practice. A survey of the salient points in the literature indicates that a solid mathematics foundation is important for engineers and that mathematics, in all its forms, is indicative of logical rigor which is the basis for developing good problem solving and analytical skills. This foregrounds the need for future engineers to have a sound understanding of mathematics (Croft & Ward, 2001; Kent & Noss, 2000; Blockley & Woodman, 2002; Trevelyan, 2007; Lopez, 2007). Mathematical skills can be developed through the use of enhanced approaches to teaching that take cognizance of the multitude of issues that impact learning. Some of these issues include student needs, diversity, technological advances and current research in engineering education (Lopez, 2007). Croft and Ward (2002) note that mathematics is amongst the few modules prescribed as a pre-requisite to engineering courses and which underpins all engineering courses. Trevelyan (2007) acknowledges that accurate prediction in the engineering environment is made possible by the methods and language offered by mathematics, further underscoring its fundamental importance to engineering practice. In addition, it enables the development of practical solutions dependent on mathematical analysis and demonstration. Studies that have focused on the use of mathematics in engineering contexts show that procedures, models and concepts are strongly embedded in engineering applications (Bissell & Dillen, 2000; Kent & Noss, 2002, 2003; Roth, 2003).

5.1.3 Consequences for engineers of a lack of mathematical competencies. Mathematics is viewed as the "language of scientific communication" and a lack of mathematical facility impedes engineers from engaging in scientific change and development (Blockley & Woodman, 2002, p. 1). The consequences thereof may lead to misunderstanding or completely missing the engineering phenomena. Students entering engineering as a field of study seem to be lacking the mathematical competencies required for the study of technical courses in higher education (Pollock, 2002; Springer, Stanne & Donovan, 1999). This lack of mathematical competencies seems to extend to the working world where some studies have shown that even after graduation mathematical skills essential to engineering practice have been found to be widely lacking among practicing engineers (Blockely & Woodman, 2002; Henderson, 2003; Lopez, 2007). The lack of mathematical competencies in the working world is exemplified by mathematical deficits which potentially lead to engineering errors.

Surveys that were conducted with software engineers reveal that their knowledge of mathematical logic and discrete mathematics was inadequate in practice (Henderson, 2003). Lack of mathematical competencies were also noted among civil engineers who, when using finite element modeling, made incorrect assumptions resulting in the setting of boundary conditions and non-existent degrees of freedom. Equally disconcerting is the finding that engineers often do not recognize that when attempting to model a slab using grillages, torsion will be inadequately represented. A case in point is the development of Reliability Theory, by engineers with a strong mathematical background. Although Probability Theory forms the basis of Reliability Theory, in situations where data is sparse the rigorous Bayesian approach is the preferred one despite it having a subjective albeit rigorous judgment. The Bayesian approach requires a mathematically strong engineer to adequately criticize it. However, few engineers are able to criticise the approach adequately because of their inadequate understanding of Probability Theory. This is a concern as engineers should have the theoretical understanding of mathematics, more specifically Probability Theory as handling risk is one of the most basic issues in modern society (Blockley & Woodman, 2002). Blockley and Woodman contend that the process skills of mathematics such as problem solving and mathematical and scientific communication are arguably more important than the mathematical procedures, especially since many of the routine calculations can be done using technology.

Whereas previously the focus of mathematics for engineers emphasised deductive proof, the advent of modern computers has impacted on how mathematics is used. Previously mathematical calculations were performed manually by engineers. With advancements in technology, computers can now efficiently perform lengthy calculations previously computed by engineers. The new challenge has become the emphasis from performing calculations to interpreting the significance of them within the engineering context (Blockley & Woodman, 2002). Blockley and Woodman argue that the new prominence accorded to mathematical modelling emphasizes the construction of suitable theoretical or physical models and the expression of their scientific understanding, mathematically. Expressing scientific understanding mathematically allows data to be scrutinized from many perspectives thereby enhancing their reliability.

5.1.4 What mathematics should be taught to engineers? Alpers (2011), suggests that the mathematical education of future engineers should endeavour to establish the mathematical competencies that engineers are expected to demonstrate. He identified the mathematical competencies that he saw as being necessary in terms of eight operationalised skills. These mathematical skills include: thinking and reasoning mathematically, posing and solving mathematical problems, using mathematical modeling, representing mathematical entities, manipulating mathematical symbols and communicating scientifically. Mathematics is characterized as the language that enables scientific communication as “without a facility in mathematics you cut engineers off from scientific change and development” (Blockley and Woodman, 2002, p. 1). If scientific communication is blocked by an inability to effectively convey its understanding it results in important mathematical concepts being inadequately understood (Blockley & Woodman, 2002). What mathematics should be taught to engineering students is thus of key importance.

The debate over whether mathematics, should be taught in all its abstraction or in the context of its application in engineering, is an ongoing one. The perspectives of many authors have been considered in order to identify some of the current practices used in facilitating the learning of mathematics to engineering students and some points of view will be presented in this section. As mentioned earlier in this chapter, technological advancements have impacted considerably on the engineering environment enabling the computer to perform mathematical calculations in engineering that were previously done by engineers. The view that the replacement of manually performing mathematical calculations using technology has rendered mathematics ‘invisible’ to engineers is countered by Kent & Noss (2000) who argue that technology can be used appropriately to make the mathematics ‘visible’ and understood.

Kent and Noss (2000) illustrate that despite the toolbox metaphor, mathematics is more than a collection of passive tools. They presented students with demanding mathematics that they were required to apply immediately to specific engineering contexts. They claim that the mathematics, rather than acting as a passive agent, provided a means to make sense of underlying principles of engineering, whilst at the same time creating opportunity for the mathematics to inherit the meaning drawn from the context. Be that as it may, the ability of computers to perform mathematical computations and calculations raises questions about the extent of mathematics that engineers need to learn and be able to apply. While the use of technology has obviated some of the challenges faced by engineers who lack the mathematical competencies required in engineering, it has also sparked debate over how much mathematics is necessary for students studying engineering (Blockley & Woodman, 2002; Henderson, 2003; Lopez, 2007).

The selection of mathematics to be learnt by future engineers involves consideration of both the actual mathematical topics that will be helpful in the engineering profession and the process skills discussed above. Bickley (1964, p. 381) asks “is the mathematician to teach abstract mathematics and leave the engineer to ‘apply’ it as and when he needs it”? He suggests that the answer lies in developing engineers who are better mathematicians and mathematicians who are better engineers and that enhancing the mathematical and engineering expertise of engineers can be achieved through the approach to teaching. Bickley explains that the approach requires mathematics lecturers to become familiar with the mathematics topics pertinent to engineering modules and to be able to demonstrate how these topics lend themselves to application in the various engineering modules. This means that the lecturer is expected to consider that students are future engineers who must be exposed to mathematics in a way that helps them to understand it from the perspective of engineering. Bickley acknowledges that “abstraction and generalization are the life and soul of mathematics”, and argues that examples of mathematics evident in different engineering disciplines should be given to all engineering students (1964, p. 382).

Blockley and Woodman (2002) profess that “mathematics is the ultimate form of logical rigour” (p. 1) an essential quality for engineers. They contend that the focus on getting the correct answer has resulted in stifling creative thinking in schools. Despite the focus on correct answers they note that in the current context, being able to solve problems using logical procedures is important. As learning mathematics is a sequential process with latter concepts being difficult to learn if previous layers have not been mastered, the use of logical procedures enables the engineer to develop an understanding of how to use mathematics comfortably, effectively and appropriately (Blockley & Woodman, 2002). This resonates with what Bernstein terms ‘hierarchical knowledge structures’ which means that the concepts selected should be integrated towards a common domain of knowledge that reaches higher levels of abstraction (2000).

In practice the theoretical considerations discussed above and the requirements of the professional engineering accrediting bodies that control entry to the profession are considered in developing the mathematics curriculum for the engineering degree programme. These requirements are discussed in the following section.

5.2 Mathematics Requirements of Engineering Accreditation Bodies

Advancements in engineering served as a catalyst for the globalisation of engineering (Hanrahan, 2008) and necessitated the quality assurance of alignment of engineering qualifications across the world (Case & Jawitz, 2003). The Washington Accord, first signed in 1989, is one of six international agreements that benchmarks mutual recognition for engineering education and professional engineering competence (International Engineering Alliance, 2013). The Washington Accord benchmarks the quality of engineering education amongst signatory countries and ultimately engineering degrees internationally (Islam, 2012). Signatories to the agreement and the statutory body are committed to accrediting the degree.

The Washington Accord facilitates the migration of engineers between signatory countries by ensuring the academic quality of degrees. In addition the Accord provides a set of graduate attributes whose purpose is to ensure a set of assessable learning outcomes in terms of competencies expected of an engineering graduate. The signatories to the Washington Accord are expected to comply with the graduate attributes to develop outcomes-based accreditation criteria which are supported by level statements that can attest to the outcomes being achieved. Amongst the requirements, the Washington Accord states that the quality of the engineering degree depends on the programme design, the teaching and learning process and assessment of students. Further to this the Washington Accord stipulates the knowledge profile of the engineering degree which includes “conceptually-based mathematics, numerical analysis, statistics and formal aspects of computer and information science to support analysis and modeling applicable to the discipline” (International Engineering Alliance, 2013).

Three of the countries that are signatories to the Washington Accord will be discussed here as contrasting examples to the implementation of the accord in South Africa. These countries are the United Kingdom, the United States, and Australia and their respective statutory bodies which are the Engineering Council UK, the Accreditation Board for Engineering and Technology and Engineers Australia. The primary objectives of the statutory bodies are to accredit undergraduate engineering programmes, to ensure that they are in accord with national and international benchmarks and to promote a high standard of education and professional competence of engineering practitioners (Engineers Australia, 2012, 2013; Engineering Council of South Africa, 2004; Engineering Council UK, 2010; ABET, 2011).

The Engineering Council UK stipulates that engineering graduates should be able to "demonstrate knowledge and understanding of essential facts, concepts, theories, and principles of their engineering discipline, and its underpinning science and mathematics" (Engineering Council, 2010). One of the five specific learning outcomes outlined in the document is "underpinning science and mathematics, and associated engineering disciplines, as defined by the relevant engineering institution" (Engineering Council, 2010, p. 13).

Engineers Australia is a signatory to the Washington Accord and so complies with the accreditation criteria it established. The specific mathematics content is not advised in the degree specifications but is included in the list of components outlining the accumulative learning experience as "mathematics, science, engineering principles, skills and tools appropriate to the discipline of study (> 40%)" (Engineers Australia, 2004, p. 19). The specific reference to mathematical competency is phrased thus: "enabling skills and knowledge in mathematics; physical, life and information sciences, and in engineering fundamentals must adequately underpin the development of high level technical capabilities, and in engineering application work within the designated field of practice and selected specialisations" (Engineers Australia, 2012, p. 11).

The United States accrediting body, ABET, (2011), specifies nine outcomes that engineering degree graduates should achieve. The outcome specifically related to mathematics states that a graduate should demonstrate "an ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies" (ABET, 2011, p. 2). Furthermore ABET stipulates that the engineering degree curriculum must develop students' ability to apply the mathematics learned, more specifically integral and differential calculus, in the solution of technical problems.

A comparison of the role of mathematics across the UK, USA and Australia (Table 5.1) reveals that the three countries require engineering students to demonstrate knowledge and understanding of the mathematical sciences underpinning the engineering discipline (Engineering Council UK, 2010; ABET, 2011; Engineers Australia, 2012). In addition, in the USA and Australia, the engineering students are expected to know and to apply the skills, principles and tools of mathematics appropriate to the discipline of engineering (ABET, 2011; Engineers Australia, 2012).

Table 5.1

Synopsis of the Role of Mathematics and the Engineering Curricula in the UK, USA, and Australia

Country and Accreditation body	Role of mathematics	Curriculum
United Kingdom Engineering Council UK	demonstrate knowledge and understanding of essential facts, concepts, theories, and principles of their engineering discipline, and its underpinning science and mathematics. (Engineering Council, 2010, p. 12)	underpinning science and mathematics, and associated engineering disciplines, as defined by the relevant engineering institution. (Engineering Council, 2010, p. 12).
United States of America Accreditation Board for Engineering and Technology	graduate should demonstrate an ability to apply a knowledge of mathematics, science, and engineering (ABET, 2011, p.3).	the curriculum must develop students' ability to apply the mathematics learned, more specifically integral and differential calculus, in the solution of technical problems (ABET, 2011, p.3).
Australia Engineers Australia	mathematics, science, engineering principles, skills and tools appropriate to the discipline of study (not less than 40%) (Engineers Australia, 2012, p.10).	enabling skills and knowledge in mathematics; physical, life and information sciences, and in engineering fundamentals must adequately underpin the development of high level technical capabilities, and in engineering application work

	within the designated field of practice and selected specializations (Engineers Australia, 2012, p.10).

Drawing on this, a framework was developed for the analysis of the role of mathematics and the mathematics curriculum in engineering at the SAHEI. The framework includes scrutinizing the role of the ME module in terms of whether it seeks to develop an understanding of mathematics and the ability to apply the knowledge, principles, skills and tools of mathematics in the engineering disciplines. The role of the ME module at the SAHEI compares favourably with the role of mathematics envisaged for engineers globally. At the SAHEI students are required to demonstrate competence in applying their knowledge of mathematics, basic science and engineering sciences from first principles to solve engineering problems. Solving from first principles is a reference to solving mathematical and engineering problems using fundamental principles of mathematics. What stands out is that, of the four countries mentioned above, South Africa is the only one that stipulates that mathematics problems in engineering be solved from first principles.

Scrutiny of the role of mathematics across the accrediting bodies in the United Kingdom, United States of America, Australia and South Africa reveals that the four countries share a common understanding of the role of mathematics in engineering education and practice. All four countries view the role of mathematics as central to engineering education. These countries emphasise the need for engineering students to have an understanding and knowledge of mathematics and to be able to apply mathematics in engineering contexts. As these countries are signatories to the Washington Accord, they are compliant with its requirements.

In this section I describe the role of the ME module in engineering at the SAHEI since I contend that the role of mathematics in engineering at the SAHEI influences how teaching and learning engineering students is approached in the ME module. The role of mathematics in engineering was investigated using qualitative methods that supported the collection of data necessary to appraise the role of the ME module in engineering. The principal data were collected using policy documents from the department of mathematics, the institution, ECSA, National Plan for Higher Education (NPHE) and electronic mail communication with academics lecturing in engineering. The findings of this phase of the research were derived through analysis of documented data and qualitative analysis of correspondence with academics and are presented next.

The Washington Accord requires the engineering degree to comprise a knowledge profile demonstrating “conceptually-based mathematics, numerical analysis, statistics and formal aspects of computer and information science to support analysis and modeling applicable to the discipline” and while it does not stipulate the role of mathematics in engineering, it does refer to the engineering degree programme as preparing the engineering graduate to “apply knowledge of mathematics, [together with] science, engineering fundamentals and an engineering specialization … to the solution of complex engineering problems” (Graduate Attributes and Professional Competencies, 2013, p. 9).

Of the five characteristics of engineering work identified, ECSA highlights the salience of mathematics in engineering by making reference to the distinctive competencies required: (a) investigating and solving engineering problems and designing solutions and (b) applying knowledge and technology based on mathematics, basic sciences … and contextual knowledge (ECSA, 2005). Those who graduate from the institution will become professional engineers by virtue of their degree and are expected to perform complex engineering work characterized by the application of a significant range of fundamental principles, enabling the development and application of new technologies and the promotion of advanced designs and design methods. The objectives of engineering education are discussed in the light of the outcomes stipulated by ECSA in their accreditation criteria for professional engineers: problem solving, design and synthesis, engineering methods, critical awareness of the impact on society and environment, professionalism and independent learning. In South Africa the National Qualifications Framework (NQF) is the driving force behind the Higher Education Qualifications Framework (HEQF) which directs the engineering degree qualifications. The process undertaken to assure the quality of the engineering degree programme entails quality assurance by the Higher Education Qualifications Committee (HEQC) (a committee under the Council on Higher Education). The Memorandum of Understanding is an agreement required by the South African Qualifications Authority (SAQA) and is signed between the CHE and the Engineering Council of South Africa (ECSA) who accredit new programmes and assure the quality of existing engineering programmes respectively (Hanrahan, 2008).

In South Africa ECSA governs the quality and accreditation of the engineering programmes in higher education in accord with the Memorandum of Understanding and the Washington Accord (ECSA, 2001). ECSA stipulates that the purpose of the engineering degree is to develop in graduates "a thorough grounding in mathematics, basic sciences, engineering sciences, engineering modeling, and engineering drawing together with the abilities to enable applications in fields of emerging knowledge" (ECSA, 2004, p. 2). The required number of credits that ECSA requires in the Mathematical Sciences is projected to be between 49 and 57 depending on the area of specialisation in engineering (CHE, 2013, p. 186). ECSA exit level outcomes 1,2,5,6 and 9 are distinctly listed as the learning outcomes of the ME module which are to be achieved at the most basic level. An elaboration of the exit level outcomes reveals that students should demonstrate competence to: a) identify, assess, formulate and solve c*onvergent* and *divergent* engineering problems creatively and innovatively (problem solving); b) apply knowledge of mathematics, basic science and engineering sciences from first principles to solve engineering problems (application of scientific and engineering knowledge) ; c) use appropriate engineering methods, *skills* and tools, including those based on information technology (engineering methods, skills and tools) ; d) communicate effectively, both orally and in writing, with engineering audiences and the community at large and (professional and technical communication) e) engage in independent learning through well-developed learning skills (independent learning ability). Furthermore, the programme is required to have a coherent core of mathematics, fundamental sciences and key engineering sciences that forms the basis for lifelong learning. This last statement indicates the type of graduate attributes that should be demonstrated. Furthermore, ECSA specifies the core and specialist requirements:

> The programme shall have a *coherent core* of mathematics, basic sciences and fundamental engineering sciences that provides a viable platform for further studies and lifelong learning. The coherent core must enable development in a traditional discipline or in an emerging field. (ECSA, 2004, p. 3)

My understanding of the terms 'viable platform for further studies', 'coherent core' and 'enabling development in a traditional discipline or emerging field' suggests that mathematics should provide a basis for postgraduate study. The ME module does not do this due to the removal of aspects crucial to the study of traditional or academic disciplines being removed thereby 'diluting' the mathematics included in the module. For entry into the engineering degree, ECSA stipulates that the minimum learning assumed to be in place should comply with the entry requirements of the degree-provider. It does not specify the curriculum content suggesting a weak classification of content. The exit level outcomes that graduates are expected to attain upon completion of the engineering degree, are reflected in Table 5.2

Table 5.2

ECSA Exit Level Outcomes for the South African Engineering Degree

	Exit level outcome Learning outcome - Level descriptor	The candidate must be able to demonstrate
1	Problem solving	competence to identify, assess, formulate and solve convergent and divergent engineering problems creatively and innovatively
2	Application of Scientific and engineering knowledge	competence to apply knowledge of mathematics, basic science and engineering sciences from first principles to solve engineering problems
3	Engineering Design	competence to perform creative, procedural and nonprocedural design and synthesis of components, systems, engineering works, products or processes
4	Investigations, experiments and data analysis	competence to design and conduct investigations and experiments.
5	Engineering methods, skills and tools.	competence to use appropriate engineering methods, skills and tools, including those based on information technology.
6	Professional and technical communication	competence to communicate effectively, both orally and in writing, with engineering audiences and the community at large.
7	Impact of Engineering Activity	critical awareness of the impact of engineering activity on the social, industrial and physical environment.
8	Individual, team and multidisciplinary working	competence to work effectively as an individual, in teams and in multidisciplinary environments.
9	Independent learning ability	competence to engage in independent learning through well-developed learning skills.
10	Engineering Professionalism	critical awareness of the need to act professionally and ethically and to exercise judgment and take responsibility within own limits of competence.

The responsibility lies with universities to take cognizance of the literature regarding the relationship between mathematics and engineering, and the statuary requirements of the accreditation bodies in their countries in designing the mathematics curriculum for engineering students. Some examples of such curricula are discussed in the next section to provide some comparison and contrast with the curriculum at the SAHEI.

5.3 Mathematics in Engineering Curricula Nationally and Internationally

Moore's (2004) perspective, that curriculum drives what happens in education is illustrated in the following excerpt:

> At the heart of the educational process lies the curriculum and the crucial question, "What should we teach?" Whatever we intend to do with education, or believe is happening because of it, occurs by virtue of the transmission of knowledge intended to transform the learner. (Moore, 2004, p. 147)

In the USA the drive to reconceptualise engineering and science education was in response to swift changes in technology, industry and an increasingly competitive global market. This was accomplished through collaboration between Government and industry to initiate curriculum reform through several projects run under the auspices of the National Science Foundation (NSF). The NSF funded staff development initiatives to train science and engineering educators to implement and monitor interventions that were put in place to realise the reconceptualised curriculum (Jawitz, 1999). Dialogue between industry, higher education and ABET resulted in a shift to an outcomes-based accreditation model with, once again, engineering educators being trained to implement the new accreditation system, use assessment and evaluation instruments to achieve the outcome-based objectives. In Australia government initiatives to ensure the quality of immigrant engineers and on-going research in engineering education led to a national review of engineering education. That resulted in an outcomes-based approach analogous to that adopted by ABET (IEAust, 1997). Implementation of curricular changes in redesigning course descriptions in terms of outcomes is attributed to the focus on quality assurance of the engineering degree (Jawitz, 1999).

In South Africa, Jawitz reports in his article that engineering academics offer different perspectives on the reasons for the shift to an outcomes-based accreditation, with some citing alignment with international trends as indicated by the Washington Accord and ECSA claiming that the shift was in response to the need to distinguish between the products of the universities (engineering degree) and universities of technology (engineering technician and technologists) (Jawitz, 1999). This study will, in part, determine from a South African perspective whether and how the ME module in the SAHEI provides learners with the opportunity to meet the ECSA exit level outcomes.

Hanrahan (2008) contends that engineering encompasses solving crucial problems related to the economy and society and that the preparation of engineers thus includes acquiring a "body of knowledge" based on mathematics, basic and engineering sciences and distinct competencies. These distinct competencies comprise the identification, analysis and solution of problems, managing, monitoring and measuring the effect of engineering activities on people and the environment whilst exhibiting ethical and responsible actions. These defining characteristics distinguish the professional engineer from the engineering technologist and technician. Professional engineers in South Africa are distinguished by their proficiency in problem solving and creatively developing innovative solutions through application of fundamental engineering principles. These fundamental engineering principles are grounded in mathematical and physical sciences (ECSA, 2004).

Lopez (2007) has shown in her review of the literature that engineering is constantly evolving in accord with developments in technology. In keeping with this is the need to review and redesign the curriculum to respond to the changes in engineering and technology. These changes impact significantly on the engineering curriculum and how engineering education is approached. In this review, I have demonstrated that, globally, mathematics is acknowledged as being fundamental to the study of engineering and to engineering practice. The literature also shows that global trends in engineering education impact on curriculum design (Jordan & Yeomans, 2003), and that curricula are often reengineered to suit the needs of progress in technology and the changing needs of society (Lopez, 2007). While some universities, in response to trends in engineering and needs of industry, have changed their curriculum from being content-driven to competency-based (SEFI, 2011), others have adopted different approaches some of which include problem-based learning, computer-based methods and traditional lecture-style methods (Kirschner, Sweller and Clark, 2006; Kolmos, 2006).

Bajpai (1985) noted the need to constantly re-evaluate the mathematics that is taught to engineering students to keep up with changes in technology and the increasing sophistication of engineering subjects that require more mathematical facility. He was concerned that mathematics was taught to engineering students in a compartmentalised way, and although it presents a tidy way of presenting the mathematics, his concern was that it fell short on illustrating how the mathematics fits into the solution of engineering problems. He suggested that real-life engineering problems require a combination of techniques which the compartmentalised way of teaching mathematics topics does not provide potentially depriving students of the opportunity to appreciate the interrelationships between different techniques that an integrated approach professes to achieve (Bajpai, 1985). The integrated approach exposes students to different techniques and the advantages and disadvantages of each thereby enabling them to use techniques in a variety of combinations in solving problems. Bajpai contends that teaching analytical and numerical methods of solving second order differential equations in separate courses should be discouraged as it is not the best teaching strategy. Teaching analytical and numerical methods in a single course are more beneficial to student learning as that would enhance their ability to use the techniques independently of each other or in combination. The integrated approach allows students to develop an overall understanding of the mathematics and lends itself to the combination of "analytical, numerical, statistical, computer … and digital techniques, in … teaching of a topic" (Bajpai, 1985, p.420). Working with a team of experienced and committed teachers, Bajpai developed and refined mathematical material supporting the integrated approach.

In Europe, SEFI is an institution whose purpose is to develop and modify systems of engineering education to meet the needs of a constantly changing industrial landscape due to progress in science and technology. SEFI founded the Mathematics Working Group (MWG), made up of engineers and lecturers in engineering mathematics from higher education institutions in most countries. The primary task of the MWG was to "investigate development and innovation, the impact of computers, and to examine the mathematical toolkit of engineers" (Barry & Steele, 1993, p. 224). They established that a core mathematics curriculum for engineers should include: analysis and calculus, linear algebra, discrete mathematics, probability and statistics. In addition, SEFI recommended that there should be an integration of numerical mathematics into the curriculum. To take this further, mathematics and engineering educators from HEIs across Western Europe worked collaboratively to develop the common curriculum (Barry & Steele, 1993). They note that the advent of the computer was the predominant factor signifying the need for a redesign of the mathematics curriculum for engineers. Based on this and the subsequent increase of computer usage in engineering environments, SEFI envisaged the need for an engineering education that prepared engineers to be proficient in computer programming, as that would enable them to modify or extend computer software to meet the needs of the engineering environment. Such programming proficiency would require engineers to have knowledge of discrete mathematics.

5.4 The Role of Mathematics in the Engineering Curriculum at the SAHEI

In this section I describe the role of the ME module in engineering at SAHEI through the lens of the various stakeholders in engineering, The role of mathematics in engineering at the SAHEI was investigated through the analysis of policy documents, interviews with academics lecturing in mathematics, the Head of the School of Mathematics and electronic mail communication with academics lecturing in engineering. The institutional policy documents of relevance to the intended role of mathematics in the engineering curriculum included the senate approved Module template and the SAHEI CoAES handbook.

5.4.1 Policy documents. In the module template the ECSA exit level outcomes 1,2,5,6 and 9 are explicitly listed as the learning outcomes of the ME module, which are to be achieved at the most basic level. An elaboration of these exit level outcomes reveals that engineering students should demonstrate competence to: a) identify, assess, formulate and solve c*onvergent* and *divergent* engineering problems creatively and innovatively (problem solving); b) apply knowledge of mathematics, basic science and engineering sciences from first principles to solve engineering problems (application of scientific and engineering knowledge) ; c) use appropriate engineering methods, *skills* and tools, including those based on information technology (engineering methods, skills and tools) ; d) communicate effectively, both orally and in writing, with engineering audiences and the community at large and (professional and technical communication); and e) engage in independent learning through well-developed learning skills (independent learning ability). The SAHEI CoAES handbook stipulates that the aim of the ME module is to "introduce basic mathematical concepts of differential and integral calculus" (SAHEI, Handbook, 2012).

5.4.2 Interviews with academics. In the interview with the head of school it emerged that the role of mathematics is to "develop a way of thinking for the engineers". He also indicated that the pure mathematics module would be relevant in achieving that (Interview, HoS, 2012). Dr A described mathematics as "a language which is used to the applied sciences example, physics, biology, engineering" and explained the role of mathematics as "the way I see it, its solving for x". He mentioned that this was different from Applied Mathematics which is "giving physical interpretation to it" (Interview, Dr A, 2012). This statement suggests a view of mathematics that is instrumental and more aligned to that of a toolbox. During the interview Dr B was asked what the role of mathematics was, and responded that "It's a tool for them to solve their problems, they need to use it, to use it as a tool" (Interview, Dr B, 2012). Dr C's understanding of the role of mathematics is that "maths is used to deal with problems that happen in the world", a view that also aligned to the concept of a toolbox (Interview, Dr C, 2012).

To get the perspective of engineers about the role of mathematics in the engineering curriculum, I sent semi-structured questions via e-mail to four engineers who lecture in engineering. Dr DN, the then deputy dean of Engineering, claimed that "calculus is required in every discipline of engineering and is a fundamental building block of mathematical sciences" and added that "ECSA requires all degree programmes to have a minimum component of mathematics". He also explained that while the module does build towards certain exit level outcomes, the ME module "does not meet any outcome as these are examined at exit level" (E-mail communication, Dr DN, 2012) and "almost all engineering analysis involves some mathematics. Without algebra it would be very difficult to define engineering problems, let alone analyse them … calculus is an essential part of structural analysis and all dynamic analysis" (Electronic communication, Dr CVL, 2012). Dr CVL provided a list of civil engineering modules which include all the civil engineering modules (16 ENCV 2 and ENCV3 modules in total) and which build up to the fourth year (ENCV4) modules that require the full range of mathematical abilities. Judging from the response, the evidence suggests that the role of mathematics is central to engineering. The ME module is a prerequisite for the modules done in subsequent semesters for example: Math 141 (subsequent mathematics module), Math 142 (subsequent applied mathematics module), Math 238 (second year mathematics module for engineering students) and by extension all subsequent mathematics module for engineering students including Math 239 (Applied finite mathematics).

The views on the role of mathematics in the engineering curriculum from the most overarching (the Washington Accord) down to the level of individual lecturers are summarised in Table 5.3.

Table 5.3

Summary of Data Pertaining to the Role of Mathematics in Engineering

Data source	Role of mathematics
Washington Accord	Engineering students should be exposed to conceptually-based mathematics, numerical analysis, statistics and formal aspects of computer and information science to support analysis and modeling applicable to the discipline and be able to “apply knowledge of mathematics, [together with] science, engineering fundamentals and an engineering specialization … to the solution of complex engineering problems
ECSA	To develop a thorough grounding in mathematics, basic sciences, engineering sciences, engineering modeling, and engineering drawing together with the abilities to enable applications in fields of emerging knowledge
SAHEI CoAES handbook 2012	To introduce basic mathematical concepts of differential and integral calculus
HoS (Interview, 2012)	develop a way of thinking for the engineers
Dr A Interview, 2012)	a language which is used to the applied sciences example, physics, biology, engineering
Dr B (Interview, 2012)	It’s a tool for them to solve their problems, they need to use it, to use it as a tool
Dr C (Interview, 2012)	Maths is used to deal with problems that happen in the world
Dr DN (e-mail communication, 2012)	Calculus is required in every discipline of engineering and is a fundamental building block of mathematical sciences
Dr CVL (e-mail communication, 2012)	Almost all engineering analysis involves some mathematics. Without algebra it would be very difficult to define engineering problems, let alone analyse them … calculus is an essential part of structural analysis and all dynamic analysis

The relevance of the mathematics topics engineering other modules in the engineering curriculum was ascertained in an interview with the Academic Leader and the coordinator of engineering mathematics (from the mathematics department). These are captured in table 5.4 in Appendix I.

Table 5.4

Aims and relevance of the ME module in the engineering curriculum

Topic	Use in other mathematics in the engineering curriculum	Math 1B
Elements of logic and set theory.	Not done at HC at least since the merger 2004 even though it appears in the handbook and is currently being taught at the PMB campus.	
Functions and their graphs, limits and continuity.	Crucial	This is required to understand the concept of a derivative. This is necessary to understand integration. It is used when dealing with series especially for the Taylor series – need to know the derivative.
Differentiation.		Crucial to understand integration as it is the inverse operation to the derivative
Application of derivatives to optimization and curve sketching, linear and quadratic approximation, Newton's method.		Relative rates will not be seen again – just used as an application of derivative. Curve sketching is important because the integral is the area under the curve – in order to be able to define an approximation (Rehmann sums), need to be able to generate a decent sketch of the function.
Indeterminate forms.		Not covered
Inverse trigonometric and other transcendental functions.	Integrating Using as substitution to integrate other function Series Fourier's functions Complex equivalence of these functions Laplace transforms	Techniques of integration is trig substitutions in order to be able to generate solutions using that technique need to be able to have good understanding of trig functions.

Indefinite integrals, basic techniques of integration.	Method of substitution – when they see integration again this is the first method they will check	No indefinite integrals Techniques of integrals
Definite integrals.		Definite integrals are crucial as well as the use of various other techniques to solve
Approximate integration. Applications in geometry, physics and engineering	Not covered Finding area under a curve which is a geometric application – use definite integration to find. Surface area – geometric as well	Not covered Will use to find volume of revolutions which is a geometric – volumes of revolution that form a solid.

5.5 Discussion

The perspectives of the Washington Accord, ECSA, the HoS and the SAHEI CoAES handbook are relevant to understanding the context in which mathematics operates within the ME module in the SAHEI. There is a dichotomy in the data presented with two distinct perspectives on the role of mathematics emerging. The first perspective views the role of mathematics as knowledge to be applied which is analogous to the notion of mathematics as a tool which could be used to solve complex engineering problems. The second role looks at mathematics as developing conceptual understanding with application in emerging fields of knowledge.

5.5.1 The role of mathematics in engineering. The evidence shows consensus that mathematics is central to the study of engineering as well as to engineering practice. The data generated from the interview with the HoS and document analysis (Washington Accord, ECSA) confirmed the perspective that the role of mathematics in engineering is to develop mathematical understanding. The HoS indicated that the role of mathematics was to develop a way of thinking in engineers which leads me to infer that the role of mathematics is also to develop conceptual understanding. This view is congruent with that of the Washington Accord which indicates that the knowledge profile requires ‘conceptual-based mathematics’ and suggests the kind of mathematics that should be included in the content and an approach to teaching that encourages conceptual understanding. It also describes the role of mathematics in terms of application as it states that 'knowledge of mathematics' is required to be applied in engineering contexts.

A scrutiny of the ECSA documents revealed the extent of mathematics knowledge required, but not a clear statement of the role of mathematics in engineering. However ECSA's compliance with the Washington Accord with regard to the role of mathematics in engineering is evident as it states that 'a thorough grounding' of mathematics is necessary 'together with the abilities to enable applications in fields of emerging knowledge". This suggests that the engineer requires an understanding of mathematical concepts which they should be able to apply to knowledge bases that are yet to emerge. This intimates that the engineer must be able to use mathematical concepts in fields that are 'not yet known' bringing to mind Bernstein's concept of the 'unthinkable' which he claims is a precondition for democracy (Bernstein, 2000). This hints at Young's (2009) conception of powerful knowledge which refers to knowledge that enables trustworthy explanations or, in Young's words, provides access to novel ways of thinking about the world. A discussion of access to abstract theoretical knowledge, access to powerful knowledge and the implications for students are discussed in more detail in Chapter Eight.

The views of the three academics lecturing in the ME module suggest that they believe the role of mathematics in the engineering context is for the purpose of application. Studies of teaching and learning show that how teachers approach teaching and learning is often consistent with their beliefs about mathematics (Borko, Mayfield, Marion, Flexer & Cumbo, 1997; Cooney & Shealy 1995; Kaplan, 1991; Fennema & Nelson 1997; Perry, Howard & Tracy, 1999; Peterson, Fennema, Carpenter & Loef, 1989). As such an examination of academics' beliefs about the role of mathematics is warranted. Be that as it may, other studies have revealed inconsistencies between teacher beliefs and their teaching approaches (Boaler, 2000; Hoyles, 1992; Skott, 2001). This fore grounds the need for investigating the role of mathematics in engineering as viewed from the perspective of external and internal influences. Since teachers are the implementers of the curriculum I believe their understanding of the role of mathematics in the ME module should be highlighted.

5.5.2 What mathematics should be taught? The Washington Accord stipulates the knowledge profile of the engineering degree which includes "conceptually-based mathematics, numerical analysis, statistics and formal aspects of computer and information science to support analysis and modeling applicable to the discipline" (Graduate attributes and professional competencies, 2013). In addition the fellow signatories must show equivalence in terms of maintaining and exchanging ideas on criteria, policies and procedures; encouraging best practice amongst signatories; accreditation by other signatories to facilitate recognition of graduates between signatories and given that often registering and accrediting bodies are distinct, to ensure that the registering body complies with the agreement to accredit degrees from signatory countries (Hanrahan, 2008). There is a lack of specification on what mathematics content is regarded as relevant in engineering. In that regard the framing over selection of mathematical content is very weak.

From the documentation and interviews held with the academics lecturing in the ME module, the HoS, the coordinator of the mathematics modules in engineering and the Deputy Dean, an engineer, lead to the conclusion that the ME curriculum designed for engineering students (in its current form and content) has been in place for over twenty years, was at some point agreed upon with the engineering faculty at that time and has not changed since. The HoS of Mathematics provided some insight into the relationship between mathematics and engineering. His perception of the dialogue between mathematics and engineering academics indicate that the mathematics department should have strong control (framing) over selection of content and that while engineers had too much of a voice in determining what mathematics was to be taught in the past, it needed to be less:

> Historically we've had engineering professors who were really not in favour of mathematics and my former colleagues who've retired now would always tell me that's because they did not know any mathematics when they were engineers … [they were] constantly trying to cut down the content that we have and they influenced what we had in ... I think they were allowed to do that as well.

While the HoS acknowledged that there was a need for greater communication between the disciplines of mathematics and engineering concerning the mathematics offered to engineering students:

> I think we certainly need to have better communication … because we offer more in engineering than anybody else. So I really would like to see closer interaction between engineering and mathematics.

He also indicated that with the college restructuring in 2012, the influence of engineering was being reduced: "I think since we moved into ... a college that influence has been reduced somewhat”. The HoS indicated that there was no mandate provided by the engineering faculty for what mathematics was necessary and extent of the mathematics needed: “If you talking to an actual mandate … I can't give you one”.

Dr A, who has lectured in the ME module for over two decades, noted that the content has remained consistent over that period of time as it was ‘inherited’ by the various academics who have lectured in the ME module over time. A comparison of the ME module and the first mathematics module for science students revealed some common topics and differences but most noticeably, proof of techniques are missing from the ME module (see Appendix H).

The HoS indicated that his intention to streamline the pure mathematics and the ME module since mathematics for engineers should not differ from that for science students for whom pure mathematics is a compulsory module. He acknowledged that while application of mathematics in engineering was important, proofs in mathematics were necessary for engineering in that it provides the opportunity for engineering students to develop “a way of thinking” that is necessary for engineers.

5.6 Conclusion

This chapter was informed by the literature and stakeholders in engineering and higher education for example the state or national departments of education, statutory bodies accrediting engineering degrees, academic staff and shows how these constituents work to ensure consistency and quality of the engineering degree programme. The literature survey showed that despite the ongoing debate concerning the extent to which mathematics should be taught to engineers there is consensus that mathematics plays a crucial role in engineering education and practice. It emerged that problem solving, analytical thinking, communication and lifelong learning skills are amongst the skills considered characteristics of engineers. In addition, engineering curricular approaches in the USA, Australia and South Africa were appraised showing that although change in each was driven by national need, the focus on teaching and learning from a theoretical perspective was driven by learning outcomes, quality assurance and compliance with international norms (Washington Accord) (Jawitz, 1999). To highlight the role of mathematics in engineering the evidence collected from documents

(Washington Accord, ECSA, SAHEI CoAES handbook, ME module outline, Mathematics review report) and interviews with academics were presented. Although the theoretical stance is clear, this study seeks to examine how teaching and learning is approached in the ME module. In the next chapter, I will discuss the organizational and interactional aspects of the 3 message systems (content, pedagogy and assessment) in terms of Bernstein's theory of classification and framing.

Chapter Six
The pedagogic device

The first research question which sought to determine the role and relevance of mathematics in engineering was addressed in Chapter Five. The literature and data presented established that mathematics is a critical module in engineering and that the content of the ME module compares favourably with those of the other signatories to the Washington Accord. With the role and relevance of mathematics in the SAHEI established, the second research question seeks to explore how teaching and learning is approached in the ME module. This chapter begins with an exposition of how the module is organized and reveals the SAHEI teaching and learning policy and module information. In keeping with the pragmatist stance, my ontological and epistemological orientation is evident in the data collection methods used, that is document analysis, interviews and observation and in my approach to data analysis which was conducted using deductive (Bernstein's pedagogic device) and inductive (emerging themes) approaches. The first phase of the analysis was conducted using a deductive approach to examine the module from the perspective of the structure of the three message systems (the content, pedagogy and assessment) using Bernstein's concepts of classification and framing. The structure of the module was examined in terms of the classification of content and spaces and framing over selection, sequencing, pacing and evaluative criteria. The findings together with the module requirements are presented in this chapter. This section concludes with a summary of the findings which emerged from interviews with lecturers and students, the resulting modalities of pedagogic practice evident in the practices of the lecturers and a discussion of the implications of the same for learning. The inductive approach was used to elicit a more in depth understanding of teaching and learning in the ME module. The findings of this phase of the research are presented in Chapter Seven.

6.1 Organisation of the Module

The organization of the module is discussed in terms of the SAHEI policy on teaching and learning and module information: admission criteria, student profile, duly performed, mathematics on-line, mathematics booster, lectures and tutorials, assessments.

6.1.1 SAHEI policy on teaching and learning. SAHEI through its vision and mission statements markets itself as a university of academic excellence. The mission of the SAHEI is articulated in the strategic goals of the institution, one of the goals being the achievement of excellence in teaching and learning (SAHEI, 2012b).

6.1.2 Admission criteria. Admission into higher education is based on the completion of a full National Senior Certificate qualification to be eligible for entry into degree programmes. Over and above this, the criteria to gain entry into a BSC Engineering at the SAHEI, the prospective student must have attained a minimum grade of 70% in mathematics at NSC level, indicating that a good foundation in mathematics is an important prerequisite to the study of engineering. In addition, the student must achieve at least 70 % in Physical Science and 50 % in English as a first language (SAHEI, 2012a).

6.1.3 Student profile. Data from the university database indicates that over the past six years, student numbers in engineering have increased from 515 to 666. This increase in numbers also indicates that the number of second language learners in engineering, more specifically in the ME cohort, has increased significantly. The data clearly indicates that 45% of the students are English second language students. The medium of instruction at the institution is English.

Since 2007, the number of Indian students has increased by 46 but decreased in proportion from 51% percent to 46% (Table 6.2). While the number of African students has increased from 178 to 307, a rise of 72%, in the same time frame, their proportion in terms of the designated ethnic grouping increased from 35% to 46%. Historically, a large number of African students are from rural areas, a situation propagated and enforced by apartheid policy and the government of the day. The majority of these students are accommodated in the university residences. The number of Coloured students, a stark contrast to the African and Indian students intake, has risen by 4 to a total of 9 students currently registered in the ME module, and indicating a proportional increase of 0.4%. These statistics provoke an investigation into reasons for the low intake of Coloured students into engineering. What is equally alarming is that while the numbers among African, Indian and Coloured students have increased, the number of white students decreased from 69 to 42, a decrease of 64%, further decreasing their representation by 7% as they currently comprise only 6% of the engineering cohort in the ME module. While I concede that the statistics are alarming and warrant further investigation, it is not within the scope of this study to determine reasons for the decline in the number of White students, or the low intake of Coloured students. The data indicates that while in 2007 Indian students formed the largest number and proportion of students in the ME cohort, they currently are almost equaled by African student numbers. This being said, the increase in student numbers combined with the change in student composition brought about by diversity in educational, language and social background clearly emphasise the need to understand how teaching and learning in the ME module is approached at the SAHEI.

Table 6.1

Student Distribution by Ethnic Group

Ethnic group	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Indian	262	307	292	311	432	308
African	178	170	159	231	293	307
White	69	63	46	40	63	42
Coloured	5	7	9	7	9	9
Other	1	6	1	2	1	0
Total	**515**	**563**	**507**	**591**	**798**	**666**

6.1.4 Duly performed. The Duly Performed (DP) is used as a filter for access to sit for the final examination at the end of the semester. Students who do not attain 35% as an average of class test marks will be denied a DP. According to the handbook, the DP comprises the class mark, which is an average of the class tests and an 80% attendance at tutorials. In the semester in which the study was conducted, the class mark was the deciding factor in awarding a DP. Tutorial attendance was not used to award DPs as indicated in the handbook because maintaining a register of students' overall attendance was a difficult task. The large number of students split into eight tutorial groups (according to discipline) with no real order in terms of how students signed the register (not according to student number or alphabetically as students were required to sign the register once they completed the tutorials to the satisfaction of the tutor or lecturer) making the recording of students' tutorial attendance, logistical impossible. Those who did not attain the average of 35% but achieved between 33% and 34% had the option of to appeal the DP refusal. The appeals were considered on the basis of students' written motivations.

6.1.5 Web-based support. The learning@sahei website is the official student portal for the university website. Students registered in the ME module had access to the notes, examples and additional information provided by each of the lecturers on the website. The web site contained module information, lecture notes, tutorials that was provided for students to revise their high school mathematics, additional notes and hints (about assessments), additional tutorials and solutions, test information, tests and solutions as well as mock tests, examinations, solutions and the Mathematics Booster Quiz (booster). The tutorial topics include: basic algebra, functions, intersections, unions and absolute values.

6.1.6 Mathematics booster. The booster is a compulsory, on-line quiz that all students were required to take in the first three weeks of the semester. It was developed by the teaching and learning manager and is based on mathematics content that students are expected to have covered in high school. Students are allowed to take the booster test twice within a three-week time frame to enable those who do not achieve at least 80% on the first attempt to revise and to retake the test. This was done to give students the opportunity to revise or 'brush up' on their mathematical knowledge and skills so that they could participate effectively in lectures (Dr C). Dr A and Dr C confirmed that the booster was not well-attempted during the two weeks that were set aside for it to be done. Many students, predominantly those from disadvantaged schools who did not have access to computers previously lacked the computer literacy skills required to participate effectively in the booster as they had great difficulty accessing their student profiles and gaining access to the booster on the learning@sahei website. Consequently those students did not have the opportunity to 'brush up' on their high school mathematics. In addition, due to financial issues, a large number of students arrived at university nearly two weeks late, making it logistically difficult to ensure that every student registered in the ME module had adequate opportunity to participate in the booster. It was important that students gain access to the learning site in order to prepare for some aspects of university mathematics that were dependent on high school mathematics. The resultant was a large, diverse group of students that were disadvantaged in the first instance by not being able to revise important, prerequisite knowledge and in the second, had to work on their own to catch up on content which was then more difficult to follow without access to revision opportunities. To counter this the academic leader of teaching and learning in the School of Engineering, acknowledged that the lack of computer literacy skills was a severe disadvantage to students and incorporated computer literacy as a component of the Technical Communication[1] module the following year.

6.1.7 Contact sessions with staff. Lectures and tutorials are the compulsory contact sessions with staff. Each is discussed below.

Lectures. The School of Mathematics is responsible for providing the mathematics modules required by the engineering curriculum. The academics responsible for the delivery of these modules work in the mathematics department and at the very least are required to hold a Masters qualification in Mathematics. The lecturers teaching in the mathematics module under appraisal are not engineers themselves. Dr A holds a doctoral degree in Physics, while Drs B and C hold doctoral degrees in Applied Mathematics. This is significant as the debate over what mathematics should be taught to engineers and who should teach the mathematics that engineering is reliant upon is an ongoing one in the literature as well as within the institution. This is evident in the statement made by the head of school:

> Historically we've had engineering professors who were really not in favour of mathematics and my former colleagues who've retired now would always tell me that's because they did not know any mathematics when they were engineers ... constantly trying to cut down the content that we have and they influenced what we had in ... I think they were allowed to do that as well. I think since we moved into ... a college that influence has been reduced somewhat. (Interview, HoS, 2012)

To accommodate the large number of students in lectures, the 2012 cohort of ME students (first attempt and repeating students) was divided into three groups: group A, group B and group C based on the engineering disciplines that they were registered for. Each of the three academics lecturing in the ME module was assigned a group and would take all of the lectures in that group. Academics involved in lecturing the module were responsible for conducting tutorials. The venues that lectures were conducted in were tiered and sufficiently large to accommodate the number of students that were allocated to them. They each have a long rectangular table at the front of the lecture theatre with a white board attached on the wall facing the students. There is also a screen that can be used for projecting from a data

[1] a compulsory module in the first year engineering curriculum

projector or an overhead projector. Each row of seats is a step up from the previous one with tables that facilitate note taking. The timetables for the lectures, tutorials and tutor allocations are included in Appendix C:

Tutorials. The module template indicated that the purpose of tutorial sessions was to develop problem solving skills. Analysis of the additional tutorial questions which are addressed in Chapter Seven determines whether the quality of tutorial questions provided the opportunity for the development of problem solving skills. Tutorials were planned, supervised and delivered by lecturers who were ultimately accountable for the sessions. Students were divided into tutorial groups according to the discipline of engineering for which they are registered, except where the numbers are low in which case disciplines are combined. For example, the SAHEI Intensive Tuition for Engineers students and Surveying and Agricultural Engineering students were placed in the same tutorial group. Tutors were employed to assist students during tutorials. They were predominantly postgraduate students registered for their Masters or Doctoral Degrees in Pure Mathematics, Applied Mathematics or Engineering. Dr C indicated that there was no selection criteria for choosing tutors as they "come forward themselves … we check their record [academic] do they have proper qualifications. I think it's a combination of them coming forward as recruiting". Although tutors are not trained Dr C said that their background in mathematics was sufficient for them to tutor and that they did a good job. However Dr B disagreed with this point of view as she said "some of them just explain something completely wrong and it's totally wrong" (Interview, Dr B, 2012). Tutors were given copies of the additional tutorial and the solutions prior to the tutorial session.

Of the four periods allocated to tutorials two were compulsory and were meant specifically for additional tutorials. The other two tutorial periods were optional and for the benefit of students who required special assistance (module outline, 2012). The handbook specifies that students must attend at least 80% of their tutorials if they are to obtain a DP. A register was taken at the tutorials so that attendance could be traced for DP purposes. Tutorials were held once per week for each tutorial group and began in the second week of lectures so that students could complete the week's tutorial. In addition to the tutorial exercises from the textbook which students were expected to complete prior to attending the tutorial, specific additional tutorial questions were given at the tutorial session. The additional tutorials were handed to students at the tutorial and were required to be completed to the satisfaction of a tutor before the students could sign out. The tutorial venues were tiered lecture venues with some venues being large enough to accommodate 200 students while others were small which could accommodate at most 100 seated students. The large venues despite being tiered facilitated access to peers and tutors. On the other hand, the smaller venues were less conducive to learning as ventilation was not good and students could not move about freely to access their peers or tutors. I can surmise that this made it difficult to facilitate good tutorial sessions and I believe provided a good reason for students to bunk tutorials.

6.1.7 Assessment. Assessment provides a framework within which the effectiveness of teaching and learning can be measured (Shay & Jawitz, 2005). ECSA, the statutory body, that is responsible for the accreditation of engineering programmes in higher education, stipulates that "each outcome specified … must be explicitly addressed in terms of the means of assessment and the criteria for satisfaction of each outcome at exit level. The choice of evidence and format of presentation is left to the academic identity" (ECSA, 2002). According to the HoS, the criteria that the statutory body looks for when accrediting the engineering degree programmes at the institution pertains to "course handouts and examination papers okay and they also want to know the exact procedure we go through for moderation of exams and marking of examinations. They also ask for qualifications of our staff as well". This seems to suggest the view that ECSA deems the final examinations and qualifications of academics' to be a significant factor in learning as they are the requirements for achieving accreditation. The module template identifies ECSA exit level outcomes 1, 2, 5, 6 and 9 as outcomes to be achieved at the very basic level in the ME module (Table 6.2). E-mail communication from the deputy dean, Dr DN, indicated that the ME module was to show progress towards the achievement of the ELOs (E-mail communication, Dr DN, 2012) and as such was not required to be tested in the examination.

The outcomes of the module are: Problem solving (ELO 1); application of basic and scientific knowledge (ELO 2); engineering methods, skills, and tools: selecting, applying, assessing (ELO 5); professional and technical communication (ELO 6) and independent learning (ELO 9) and are to be addressed at the lowest level.

Table 6.2

Module Assessment Matrix

	ELO 1	ELO 2	ELO 5	ELO 6	ELO 9
1. Able to explain the concepts of function, limit, continuity and differentiability and solve theoretical and practical problems arising from them	√	√	√	√	√
2. Able to calculate derivatives and anti-derivatives of elementary functions, solve appropriate problems involving trigonometric and transcendental functions and their inverses	√	√	√	√	√
3. Able to explain the concept of integrals and solve theoretical and practical problems arising from it and evaluate elementary integrals.	√	√	√	√	√

The official module assessment matrix stipulates how the content shows progress towards the achievement of the ELOs (see Table 6.2 above). Whereas the Washington Accord specifies that the learning outcomes identified must be achieved, there are many opportunities within the degree programme for the ELOs to be achieved at the level required by ECSA. The SAHEI CoAES handbook (2012) indicates that the final mark comprises a 20% weighting from tests and/ or assignments and 80% from the final examination. The only form of assessment provided were tests and the final module examination which were summative assessments.

The section above provided insight into the organization of the ME module in terms of the requirements for entry into the degree and entry into the final examination as well as the structure of lectures, tutorials and assessments. Following this the analysis of the structure of the three message systems through the lens of Bernstein’s concepts of classification and framing is presented.

6.2 Bernsteinian Analysis

As discussed in Chapter Two, Bernstein's concepts of classification and framing are used to analyse the structure of a category by examining the relations between and within categories. The term categories can include subjects, disciplines, spaces and agents. These relations refer to the degree of insulation between categories and are classified in terms of its degree of strength. Strong classification (C+) means there is little integration between categories while weak classification (C-) implies there is some integration between categories. As with classification, the concept of framing establishes the relations within categories which can be categorized into degrees of strength where strong framing (F+) means greater control over the relations than weak framing (F-). The strength of classification and framing of relations between and within categories influences how teaching and learning is approached and is thus the central focus of this chapter. The data sources which are potential influences on teaching and learning include the ECSA standards and procedures, the recommended textbook, the head of school and lecturers. These constituted the units of analysis for this phase of the study. While I had initially planned to present the data as case studies in this section, I found that as I read the data, the nuances in the data began to emerge and as I coded the data and categorised them, salient themes became apparent. This section begins with the analysis of the ME module in terms of classification of content and space. Following this the module is described in terms of its framing with respect to selection, sequencing, pacing and evaluative criteria.

6.2.1 Location of the mathematics department. The School of Mathematics and School of Engineering are located on different campuses. However the mathematics lecturers lecturing in the ME module are based at the engineering campus but in a separate building from the engineering disciplines. The first year lectures and tutorials for engineering students are held in venues that are physically separate from the rest of the engineering sciences. As such the first year students have little if any contact with their engineering disciplines in the first semester of the first year of their degree. Hence it is difficult for first year students to identify themselves as engineering students. All three of their concurrent basic science modules are situated in the same building albeit on different levels of the building. Hence there is strong separation amongst these three disciplines. As they are located in the same building as mathematics, chemistry and physical science, students take most concerns regarding their degree to the mathematic department as acknowledged by the HoS:

> the engineering students … see the school of mathematical sciences on the [engineering campus] as a haven …they ask for advice on a number of different things not only mathematics and people are helping them you know ...but we see more of the students and deal with more of the queries than we should in terms of the number of students we deal with and we are happy to do that but I don't think its fully appreciated by the engineers what impact we have on the engineering students beyond just teaching them. (Interview, HoS, 2011)

Hence there is strong classification between the disciplines of engineering and mathematics as well as that between mathematics, chemistry and physics. The hierarchy of the mathematics department within the School of Mathematics is illustrated in Figure 6.1.

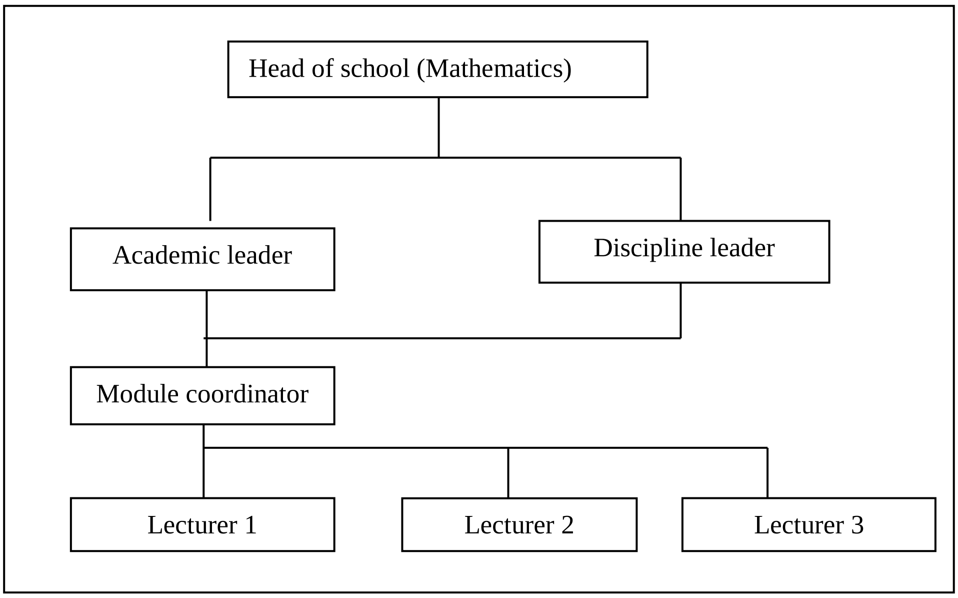

Figure 6.1 Organogram of the academic structure in the school of Mathematics

The HoS is based on a different campus from that of engineering. This campus forms the hub of the mathematics department where four of the five schools which fall within the CoAES are located. The HoS occasionally visits in at the Engineering campus as he collaborates with the mathematicians on the various campuses for the purposes of academic, disciplinary research. The HoS plans to influence the curriculum as he already indicated his intention to change the mathematics that the first year students do. The academic and discipline leaders are the liaisons between lecturers and the HoS and report to the HoS. The module coordinator is responsible for organizing all aspects of the module including drawing up the questions for tutorials, tests and the examination and influences the classification and framing of the module. The study examines the collaboration between academics on the level of teaching and learning. There is collaboration amongst academic staff with respect to research provided they share similar or the same areas of specialization. Teaching and learning mathematics to engineers is aside from mathematics per se and from research within the discipline of mathematics.

There does not seem to be much horizontal communication between lecturers in the module regarding teaching and learning approaches although they do communicate and reached consensus on tests and the final examination set by the module coordinator.

6.2.2 Recontextualisation. As mentioned in Chapter Two pedagogic discourse operates in the fields of production, recontextualisation and reproduction. The focus of this study is on teaching and learning and therefore the fields of recontextualisation and reproduction are of specific interest here. The recontextualising field, as mentioned earlier is distinguished into the ORF and the PRF. The ORF and PRF are discussed separately below. The ORF is influenced predominantly by the state and its selected agents (Bernstein, 2000). ECSA being one of those agents in “partnership with the State and the engineering profession” and which “enjoys full autonomy although it is accountable to the State” (ECSA, 2012) falls within the ambit of the ORF. The PRF comprises members of education departments and pedagogues in educational institutions (Bernstein, 2000). Hence the recommended textbook and the head of school constituted the Pedagogic Recontextualising Field (PRF). The recommended textbook and the Head of School fell within the domain of the PRF and thus formed the units of analysis to determine the degree of insulation between content on an interdisciplinary, intradisciplinary and interdiscursive level.

Official Recontextualising Field (ORF). The statutory body, ECSA, states that the purpose of the engineering degree qualification is to provide a “thorough grounding in mathematics, basic sciences, engineering sciences, engineering modeling, and engineering design together with the abilities to enable applications in fields of emerging knowledge” (ECSA, 2004, p. 2). ECSA does not specify the curriculum content except for stating that mathematics must constitute 56 credits of the total in the engineering degree. In addition, the degree should include a coherent core of mathematics which provides a “viable platform for further studies and … to enable development in a traditional discipline or in an emerging field (ECSA, 2004, p. 3). To form a viable platform for further studies in either a traditional discipline (such as mathematics) or emerging field of research (engineering), students require access to the theoretical underpinnings of mathematical concepts, suggesting that content appropriate for the academic study of mathematics should be included. However, the ME module in its current form was approved by ECSA at the most recent accreditation process in 2013 and therefore deemed fit for ECSA's purpose. From this perspective, my interpretation is that the ECSA standards and procedures system indicates a weak framing over the selection of content.

Bernstein suggests that if there is an ORF and a PRF with the PRF having some independence from the ORF, the pedagogic device becomes a site for conflict and struggle. Although ECSA, having been constituted by the Engineering Profession Act 2000 (RSA, 2005), might officially have the power to stipulate the content and approach to teaching and learning, this is not evident in the ECSA standards and procedures (ECSA, 2004b). In that regard the framing over selection of the content is weak. ECSA does however stipulate that modules which constitute the engineering degree programme must show progress towards the development of the ten ELOs. The formal curriculum document for the ME module specifies that ELOs 1, 2, 5, 6 and 9 will be addressed by the curriculum but leaves the institution responsible for achieving the ELOs, requiring only that the degree show achievement of all the ELOs upon completion. There is thus no specification as to how these ELOs should be achieved in terms of teaching and learning at the micro level of the lecture room. Hence the ORF while maintaining standards provides some leeway for the PRF of the ME module to have sufficient autonomy in terms of teaching and learning. This means that the inclusion of ELOs in the curriculum document (which is not subject to compliance with the ECSA ELOs) showed recontextualisation of the module, from the academic discipline, through to the curriculum document of the ME module. The inclusion of ELOs as part of the objectives of the module can have implications for how teaching and learning is approached.

The Pedagogic Recontextualising Field (PRF). Within the PRF agents select knowledge from the knowledge base which in this case is the academic discipline, mathematics, and in so doing regulate what mathematics is to engineers and so influence the mathematical identity of engineers. The PRF is a site for conflict and struggle over the pedagogic device, particularly since it is strongly insulated from the ORF (in this case ECSA). The ECSA accreditation process scrutinizes engineering modules for acquisition of the exit level modules. However in the ME module, ECSA only examines the final examination questions thereby ensuring its autonomy from engineering. ECSA thus shows weak control (framing) over the ME module. This provides the agents comprising the PRF of the ME module with some degree of control and autonomy over the construction of the content and pedagogic practice, and control over pedagogic discourse which regulates the construction of pedagogic texts, the relations between agents in these contexts and the texts produced by the agents at the macro and micro levels (Bernstein, 2000; Singh, 2002).

The conflict and struggle over the pedagogic device in the ME module is prevalent. Since the module is located in the engineering curriculum in higher education, which also constitutes the field of production of knowledge, the mathematics lecturers are the knowledge producers in the discipline of mathematics. However engineering lecturers are not mathematicians and demonstrate a much lower research output than mathematics indicating a low contribution to the knowledge base at the SAHEI. In addition the philosophical approaches of mathematicians and engineers to their disciplinary areas, differs fundamentally as do the knowledge structures of each discipline. Mathematical knowledge has a hierarchical structure while engineering knowledge has a horizontal structure. At the very basic level, therein lies a conflict. The ME module being 'owned' by mathematics and by virtue of its existence based on its location within the engineering curriculum (as it services only the engineering students at the SAHEI), is in a peculiar situation.

This means that the owners of the pedagogic device exert control over the regulation of the pedagogic discourse that produces the pedagogic text. In this case, being the higher education context, it pertains to the regulation at a micro level and that means within the context of the lecture room. Currently the mathematics department has ownership over the pedagogic device and is thus able to exert control over the recontextualisation and evaluation of knowledge. Singh (2002) suggests that the struggles are over theories of instruction which include the models of the students, the teacher and the student-teacher interaction. At the SAHEI, the conflict arises when engineering wants some control over the pedagogic device in terms of how much of mathematics and what mathematics is to be included in the content a situation that arose in 2011. The then newly appointed HoS (Mathematics) at that stage refused to grant the requests thereby limiting the voice of the engineers in the construction of the pedagogic texts and reaffirming ownership and control of the mathematics department over the ME module. This is exemplified in the following excerpt from the interview transcript: “if we believe this is the mathematics that needs to happen, THAT IS THE MATHEMATICS that needs to happen”! (Interview, HoS, 2011).

Clearly the control over the pedagogic device grants custody of the recontextualising field to the mathematics department who undoubtedly state that they will teach the mathematics that they believe should be taught in the way that they want to teach it. The ideology of those involved in the recontextualsing field clearly influences the construction of the discourse and serves to protect the ownership of the device as exemplified in the following statement:

> we looked at it more closely and if it is mathematics that we are trying to teach then it should be mathematics the way we want to teach the mathematics, right as mathematicians because that is our area of expertise. (Interview, HoS, 2011)

The HoS’s intention, which is a strong influence on the curriculum, is to emphasise theoretical understanding. The head of school, being newly appointed at the stage of data collection did not influence the existing curriculum, but has clear intentions to change the curriculum in the future to bring it in line with his vision of what engineers need to acquire from mathematics, making him a potential influence. His views are thus included in this study.

The curriculum as it stands was not influenced by the HoS, his intention to include the theoretical underpinning of the mathematical content in the ME module make his views important to this study as it provides some insight into the why he considers theoretical understanding important for engineers. He states that mathematics provides a way of thinking that engineers need.

Another significant component within the pedagogic recontextualising field is the textbook. To determine the influence that the textbook had on the pedagogic discourse of the lecture room, I compared the selection and sequencing of the topics in the textbook, with those included in the module schedule. From the analysis of the textbook, it was apparent that the textbook formed a template for the selection and sequencing of the content for lectures and the exercises for tutorials. The textbook and the curriculum document showed that the topics and the sequence in which they were presented were the same with two exceptions.

Topics that were in the textbook but not within the scope of the module and the sections on Elements of Logic and Set Theory which were included in the CoAES handbook, but not in the textbook. The textbook was hence a strong influence in the selection and sequencing of content in the curriculum document.

6.3 The Field of Reproduction

At the level of the lecture room, the textbook and lecturers formed part of the recontextualising field as they influenced the content that was presented to engineering students. This is not normal since the formal curriculum, stated in the CoAES handbook (2012) indicates that Elements of Logic and Set Theory are very much a part of the ME curriculum.

ECSA constituting the official recontextualising field (ORF) states that the engineering degree qualification must provide a sound foundation in mathematics and the abilities to facilitate applications in emerging knowledge fields (ECSA, 2004, p. 2) but does not specify the curriculum content. It does however expect that the curriculum should provide the potential for further studies and development in the discipline of mathematics. This suggests that the content should include theoretical knowledge which underpins the rules, formulae and definitions. Be that as it may, the pedagogic recontextualising field comprised the textbook and lecturers in mathematics and engineering who perceived the development of the content of the ME module differently from the HoS and ECSA. There was furthermore recontextualisation at the micro level in the transformation of knowledge from the curriculum document to instructional practice. As evidenced in observation of lectures and tutorials, at the micro level, lecturers' goals were not oriented towards developing the ELOs specified in the curriculum document (a detailed discussion of this is presented under the heading assessment in Chapter Seven). Recontextualisation at the different levels brought about the omission of abstract theoretical knowledge (proofs). The implications of the lack of proofs are discussed in Chapter Eight.

From the interviews and e-mail communication with lecturers, mathematics was viewed as a tool to solve problems, a view which influenced the transformation of the content (Table 4.2). Mathematics in the context of engineering was viewed as a tool by lecturers and this view manifested in their instructional practice when lecturers taught students to memorise rules, formulae and definitions and practice computational fluency: “you must by heart this” (Lecture observation, Dr B, 2012) and “they have to know the steps off by heart” (Lecture observation, Dr C, 2012), without demonstrating the theoretical underpinnings of the mathematical concepts. This resonates with Bernstein (2000) who says the pedagogic texts privileged by the field of recontextualisation undergo further transformation as they are appropriated by the lecturer and transformed into the knowledge that they present to students (Singh, 2002). The findings show that in the recontextualising field, ideology is at play on two levels. The first set of transformations occurs from the field of production in the construction of the pedagogic text. The second is the transformation of this already recontextualised pedagogic text to the field of the lecture room and tutorial sessions (Bernstein, 1996; 2000; Singh, 2002). On a micro level and within the lecture rooms, lecturers may recontextualise knowledge in the process of making the regulatory discourse more effective (Singh, 2002). The transformation of knowledge from the field of production to the field of reproduction shows that the focus on the theoretical underpinning of the mathematical topics is lost thereby diluting the mathematics that is presented to engineering students. The module then undergoes further recontextualisation at the level of transmission with the exclusion of Elements of Logic from the content (included in the CoAES handbook (2012). The implications of the exclusion of Proofs and Elements of Logic are discussed in Chapter Nine. In addition, the purpose of studying mathematics is recontextualised (and reduced) from that of developing a thorough grounding in mathematics to enable development in a traditional discipline or in an emerging field (ORF) to memorization and performing computational procedures.

6.4 Singulars and Regions

The curriculum mediates access to abstract theoretical knowledge which in turn acts as a mechanism for social stratification. Access to abstract theoretical knowledge is a precondition for democracy (Bernstein, 2000) as it provides the basis for participation in society’s conversations. Speaking in the context of vocational education, Wheelahan (2012) asserts that all curricula should be structured such that students have access to abstract theoretical knowledge. The structure of the curriculum potentially provides students with access to ’weaker’ or ‘stronger’ forms of knowledge. Thus content and the structure of knowledge become carriers for external power relations. At the SAHEI the ME module template specifies how the ME curriculum is designed, how the content is structured as well as how the content is framed (classification and framing are discussed in the next section). Wheelahan makes the point that formal curriculum documents do not provide a linear pathway that translates directly from the curriculum document through to teaching practice and ultimately to the achievement of the learning outcomes specified. The formal curriculum documents ensure the completion of the content in terms of selection and sequencing. The gap between the official curriculum and instructional practice creates a space for ideology to act. Thus lecturers recontextualise the formal curriculum according to what they deem to be important (Bernstein, 2000; Morais & Neves, 2001) albeit within the constraints of the formal curriculum. This means that the structure of the programme, the selection and sequencing of content is generally complied with. This is the case in the ME module where the selection of curriculum content and sequencing is preset together with the pacing. Hence the structure of the ME module is intact with lecturers having to comply with the curriculum document (module schedule).

The engineering degree must be accredited by the professional body (ECSA), for it to be recognized nationally and internationally. ECSA is the professional body that professional engineers must register with. Hence accreditation of the degree is of importance. ECSA accreditation is significant to the curriculum as it impacts on the engineering degree programmes requiring that they demonstrate how all the modules within each engineering degree programme build towards the attainment of the ten ELOs that ECSA specifies. The formal curriculum in its design and structure is reflective of the requirements of ECSA. In this instance, the ELOs of the ME module (ELOs 1, 2, 5, 6 and 9) reflect the module’s commitment to the development of the required ELOs. However while the ELOs were specified in the formal curriculum document, there was little evidence that instructional practice and assessment were specifically aimed at developing them. The main goal was to get students to pass the module.

Academic disciplines are regarded as singulars that are constituted by strongly classified domains of knowledge that are “narcissistic, orientated to their own development, protected by strong boundaries and hierarchies” (Bernstein, 2000, p. 52). Mathematics is an academic discipline which fits the profile of a singular. This means the academic discipline of mathematics consists of specific languages with rules about what constitutes the knowledge domain and how knowledge is to be created. In higher education the space in which the preparation of students to enter a field of practice, such as engineering, is referred to as a 'region'. In the SAHEI, engineering is the space in which students are prepared for the practice of engineering and is therefore referred to as a region. Engineering sits between the academic disciplines from which knowledge is drawn (one of them being the discipline of mathematics), and the field of engineering practice. However the position of the ME module is peculiar since it is difficult to characterize it as a singular or a region. This is because the ME module originates from the academic discipline of mathematics and has been recontextualised for the engineering curriculum. The ME module is strongly insulated in terms of its content (completely mathematical). This means that it has some qualities of a singular but due to the lack of theoretical underpinning, it cannot look inward towards itself or to its own development yet its strong classification means that it does not look outward towards the field of engineering. The ME module unlike 'normal' regions is not constituted from many singulars but is recontextualised from the academic discipline of mathematics albeit without proofs, and is specifically for engineering students. Furthermore, the ME module being a component of the engineering curriculum must show progress towards developing some of the ELOs. The curriculum document reflects ELOs 1, 2, 5, 6 and 9 as those that the module will address at the very basic level. Hence engineering does exert some influence on the ME curriculum. From the evidence presented, although the ME module has a singular relationship with the academic discipline of mathematics it is referred to as a region. This has implications for ownership of the pedagogic device as the peculiar location and constitution of the ME module makes it a site for conflict and struggle (Bernstein, 2000). This was discussed in the previous section.

Wheelahan (2008) asserts that academic qualifications aim to induct students into the knowledge domain specific to that discipline. The aim of professional qualifications is to induct students into the practice of the profession, in this case, into the practice of engineering as well as to provide the theoretical knowledge that underpins practice. In the ME module the tools of the trade are provided by way of the rules, formulae and definitions but the theoretical underpinning of the mathematical concepts are lacking from the curriculum. This is contrary to the expectation that engineering as a professional degree should integrate application with theoretical knowledge. The consequence is that students are not enabled to integrate and synthesise practical and theoretical knowledge.

6.5 Classification

Classification refers to the strength of the boundaries between categories. To determine the strength of classification in the module, I analysed the degree of insulation between categories.

6.5.1 Classification of content. The analysis of the module in terms of classification thus looked for integration of content across different modules that first year students were registered for, between sections and topics within the module and between the content and everyday knowledge. The units of analysis were the textbook, the curriculum document, interviews with academic staff and observation of lectures and tutorials. These are dealt with separately below.

6.5.2 Textbook. Analysis of the textbook revealed that classification of content on the interdisciplinary, interdiscursive and intradiscursive levels is predominantly strong. The textbook was analysed to determine the extent of classification of the content with regard to interdisciplinary, intradisciplinary and interdiscursive relations, I identified the chapters, sections and tutorial exercise that students were required to engage with (from the module outline). I then searched across the theory, examples and tutorial exercises from the textbook to determine whether they made reference to other modules, other sections or topics in the same module or real world applications. This allowed me to determine the degree of insulation of the content in the ME module. A scrutiny of the sections recommended to students revealed no mention of applications or problems in physical science, geometry or engineering as indicated in the SAHEI CoAES handbook (2012).

To determine whether the problems allocated to students in preparation for the weekly tutorial sessions consisted of problems from other disciplines or between every day and disciplinary knowledge, a scrutiny of the tutorial problems from the textbooks, additional tutorials and assessments was conducted. In scrutinizing the textbook I considered the illustrations on the cover, the tutorials problems that were allocated from the textbook and focused on the Squeeze theorem as that was the section identified by academics as being one of the sections that students had most difficulty understanding. I looked at the title of the book, the illustration on the cover, the inner page of the front cover, the table of contents, the preface, notes to the students, instructions indicating how the book is to be used and an explanation of what calculus is as well as the tutorial problems that students were asked to solve in preparation for the tutorial. The title of the book is Calculus: A complete course. The title in itself suggests that calculus is a course that can be taught and learned in isolation from other concepts in mathematics. The textbook cover has a picture of the landscape of a desert, or what looks like a barren piece of land. There is no relation between mathematics and the illustration on the cover except for the title of the textbook. The first three pages from the inner front cover consist of mathematical formulae separated under the various sections in mathematics, for example, differentiation rules, elementary derivatives and trigonometric identities. The rules, derivatives and formulae are listed clearly according to the different sections that they fall under.

Here I found no reference to other subjects or engineering in the mathematics that was presented in the book. The preface indicated that calculus is a 'human legacy' (p. xii) and is presented as "the centerpiece of human legacy", universal in its cultural significance, and as "essential to basic human thought in engineering, science, ..." (Adams & Essex, 2010, p. xii). They acknowledge that this edition of the book being the 7^{th} edition (the first being in 1940) is still relevant because the mathematics "is still the same". The only differences the authors note are that the 7^{th} edition demonstrates more examples, applications, exercises, more elaborate diagrams and is more colourful with many references to extra resources "aimed at giving the beginning student every edge in learning this venerable and important material". The authors note specifically the application of differentials and partial derivatives to thermodynamics, to show that "simply straightforward applications in mathematics" is used (Adams & Essex, 2010, p. xii). This provides a link to Physics. The note to students is to read, re-read and to consult with the tutors and teachers if necessary. But it also claims that students may not be able to do all the problems as "only a few very gifted students will be able to do them" (p. xiv) using the geometry, physics and engineering application in the exercises, illustrations or activities. The table of contents distinctly listed the different sections contained in the textbook with no reference to other subjects or disciplines. I looked through the tutorial exercises allocated for each tutorial to search for evidence of interdisciplinary (isolation from other subjects), interdiscursive (isolation from other discourses or disciplines) and intradiscursive (isolation between various topics or sections within the content) relevance. Table 6.3 summarises the extent to which the textbook integrates the ME content on the interdisciplinary, intradisciplinary and interdiscursive levels.

Table 6.3

The Criteria and Indicators Used to Analyse the Extent to Which the Text Book Integrates ME Content on an Inter-Disciplinary, Inter-Discursive and Intra-Discursive Level. (Adapted from Nsubuga, 2009)

Criteria	**Indicator**	**Inter-discursive (everyday/ vertical)**	**Inter-disciplinary (other modules)**	**Intra-discursive**
1.Book cover	Reference to other subjects, sections or everyday knowledge on the book cover	No mention of applications (C++)	No mention of applications (C++)	No mention of applications (C++)
2.Illustrations	Reference to other subjects, sections or everyday knowledge in chapters 1 to 5.	No evidence of illustrations including other discourses(C++)	No evidence of illustrations including other modules(C++)	No evidence of illustrations including other sections/ topics (C++)
3. Activities	Reference to other subjects, sections or everyday knowledge in chapters 1 to 5	No mention of other discourses in activities (C++)	No mention of other modules in activities (C++)	No mention of other sections/ topics in activities (C++)
4. Revision questions	Reference to other subjects, sections or everyday knowledge in chapters 1 to 5	No mention of other discourses in activities (C++)	No mention of other modules in activities (C++)	No mention of other discourses in activities (C++)
5. Index	Reference to other subjects, sections or everyday knowledge in the index.	While applications to other disciplinary fields are made in chapters 7.6 and 7.7 theses were not within the scope of the module and were not included in the module outline (C++)	While applications to other modules are made in chapters 7.6 and 7.7 these were within the scope of the ME module (C++)	While applications to other sections/ topics fields are made in chapters 7.6 and 7.7 theses were within the scope of the ME module (C++)

Classification on all three levels was very strong as the appraisal of the tutorial exercises specified revealed no evidence of the criteria mentioned in the table it is evident that from those sections in the textbook that were within the scope of the module syllabus (according to the module outline) the classification of the content was very strong on all three levels.

While theoretically the SAHEI handbook for 2012 distinctly states that in the ME module the content includes applications in geometry, physics and engineering, in practice this was not evident in the selection of tutorial exercises that were included in the module outline in the recommended text book. An analysis of the chapters in the recommended text book which fell within the scope of the ME module (as indicated in the module outline) revealed no indication of connections with other subjects, other disciplines or between sections within the module. In other words the classification between discourses was very strong with regard to the tutorial exercises. For example, in Chapter 1, the exercises in section 1.2 are preceded with examples showing the need for the concept of a limit. This is achieved inductively using many examples that are worked out using the same procedure. After many repetitions, the definition of a limit is provided:

> If ***f(x)*** is defined for all ***x*** near ***a***, except possibly ***b*** itself, and if we can ensure that ***f(x)*** is as close as we want to ***L*** by taking ***x*** close enough to ***a,*** but not equal to ***a,*** we say that the function ***f*** approaches the limit ***L*** as ***x*** approaches ***a***, and we write
>
> $$\lim_{x \to a} f(x) = L .$$
>
> (Adams, 2003, p. 65)

The squeeze theorem is defined as follows:

> Suppose the $f(x) \leq g(x) \leq h(x)$ holds for all ***x*** in some open interval containing ***a***, except possible at ***x = a*** itself. Suppose also that $\lim f(x) = \lim h(x) = L$
> then $\lim g(x) = L$ also. Similar statements hold for left and right limits. (Adams, 2003, p. 69)

Examples illustrate application of the Squeeze theorem (procedural) with the problems that are solved being context independent. The exercises associated with this section are all context independent and straightforward problems requiring the same procedure to be performed on each problem. For example:

> Suppose the $\lim_{x \to 4} f(x) = 2$ and $\lim_{x \to 4} g(x) = -3$. Find:
>
> **a)** $\lim_{x \to 4} (g(x) + 3)$ b) $\lim_{x \to 4} x \cdot f(x)$ **c)** $\lim_{x \to 4} (g(x))^2$
>
> (Adams, 2003, p. 71)

Similarly, all examples in these exercises were of the same type, context independent, and procedural. While certain chapters in the recommended text book were marked as Applications in Physics (Chapter 7.6) and Business, Finance and Ecology (Chapter 7.7), these chapters were not included in the scope of work for the ME module.

In summary, an appraisal of the recommended text book, tutorial exercises and additional tutorials exercises revealed that the content presented in the book are context independent problems that are procedural in nature. The problems included in the tutorial exercises were context independent, thus showing no relevance to other sections, subjects or everyday knowledge. The chapter continued in a similar fashion for all of the sections relevant to the module. From the exercises and chapters that were recommended for reading in preparation for lectures, there was no evidence of relations between sections, between mathematics and everyday knowledge or between mathematics and in other subjects. Hence the evidence collected from the textbook showed that classification of the content, tutorials exercises and problems in the textbook on the interdisciplinary, interdiscursive and intradiscursive levels exhibited very strong classification indicated as (C++).

6.5.3 Classification of content: observation and interviews. The classification of content based on observation is discussed here. To determine the classification of content, the analysis was conducted on an interdisciplinary, intradisciplinary and interdiscursive level. On an interdisciplinary level, Dr A draws on some problems from physics and mechanics. He reminded students of the topic called Diffraction, from the grade 12 NSC syllabus and describes how real, natural and integer numbers are relevant to that section:

> Describe for instance the diffraction pattern through a single slit … what would it look like [Dr A describes what it will look like] … if you had to look at the location of fringes … it corresponds to n equal to zero, n equal to plus or minus one, n equal to plus or minus two, that’s a positional or angular displacement. So that’s where these numbers come in. Very, very important! (Lecturer interview, Dr A, 2011)

The boundary between mathematics and other subjects is strong as he often mentions how the ME content discussed in that lecture fits in with other modules. As such classification on an interdisciplinary level is weak (C-). Classification on an intradisciplinary level is strong (C+) as there is little connection between topics within the module except if it is to justify the current method: “but in differentiation later on order will matter”. (Observation, Dr A, 2012). Observation revealed no indication of the use of the mathematics in an everyday context and so the interdiscursive classification is described as very strong (C++). These findings stand in contrast to those of Dr B as observation revealed no evidence of integration on an inter-disciplinary, intra-disciplinary or inter-discursive level. This indicates a very strong insulation between mathematics and other subjects in the curriculum (C++), between various topics in the ME module (C++) and between academic and everyday knowledge (C++). Dr C’s lectures exhibited very strong classification on an interdisciplinary (C++), intradisciplinary level (C++) and on an interdiscursive level (C++). The next paragraph discusses the classification of content evident in interviews and shows that there were mixed responses to the question asking whether they were able to show the relevance of mathematics in other contexts. Classification of content in tutorials was very strong as reference to other subjects, topics and everyday knowledge was not included in the tutorial problems which render the classification as very strong.

The following statement captures what Dr B and Dr C felt about integrating the content of the ME module with other disciplines: “We perceive each subject as separate and not connected … and very specialized” (Interview, Dr C, 2012). The lecturers indicated that they regarded the content as separate from other disciplines as there was no time to draw in examples that showed the application of mathematics in other contexts. Their statements confirmed the findings from observation of lectures, that on all three levels classification was very strong (C++). On the other hand, Dr A indicated weak classification when he said that he looked “at examples in the real world and then … try to relate specific sections to those real examples” (Interview, Dr A, 2012). The findings across observation and interviews were consistent with regard to classification of content.

6.5.4 Classification of space: Lectures and tutorials. Classification of space was examined in terms of the insulation between inside and outside spaces as well as within the lecture venue. The classification between inside and outside space was very strongly classified (C++) as every lecture takes place in the lecture venue. This is exemplified by Dr A who said “there are rules here. Lots of rules! ... I will walk out of my lecture and if I find you outside when you’re supposed to be inside, you’re going to be in trouble” (Lecture observation, Dr A, 2012). The classification of internal space in Dr A and Dr C’s s lectures was strong (C+) as they generally conducted lectures from the front of the venue while students were seated in rows. There were designated spaces for lecturers and students which were neither lecturer nor students transcended except occasionally when both Dr A and Dr C walked through the aisles to interact with students. The classification of internal space in Dr B's lectures was very strong as the space allocated to lecturer and students was very distinct at all times during lectures (C++).

Classification of space within Dr A's tutorials was weak (C-). Students could walk about and work with other students, sit in groups, approach the lecturer and tutors at the front of the lecture venue generally reserved for staff. Dr A and tutors walked about assisting students upon request, checking students' work and whether they needed assistance. This was the same for the tutorials conducted by Dr C and Dr B. However, in Dr A's tutorials classification of space between inside and outside was very strong (C++) as tutorials were strictly within the lecture venue. Dr B and Dr C exhibited weak classification over inside and outside spaces in tutorials as students were allowed to walk in and out of the venue and work outside the venue if they wished (C--).

6.6 Framing

Framing refers to the degree of control over selection, sequencing, pacing and evaluative criteria. To determine the framing over selection, sequencing, pacing and evaluative criteria in the module, I analysed the degree of insulation within the module. ECSA which constitutes the ORF for the engineering degree programme is discussed next.

6.6.1 Official recontextualising field (ORF).

ECSA stipulates 10 exit level outcomes that engineering degree graduates should demonstrate. Exit level outcome 2 which is the application of scientific and engineering knowledge expects students to demonstrate "competence in applying knowledge of mathematics, basic sciences and engineering sciences from first principles to solve engineering problems" (ECSA, 2004, p. 4). On the basis of the ECSA standards and procedures system, engineering degree programmes require a thorough grounding in mathematics with competence in applying it to solve engineering problems. It does not state whether acquisition of the ability to apply this mathematical knowledge must be acquired in the mathematics class. In my view, the teaching approach implies the selection of content, for example if application in engineering contexts is required then there will have to be integration of content to include contextualized problems thereby weakening the framing of the module. To quote Bickley, “is the mathematician to teach abstract mathematics and leave the engineer to ‘apply’ it as and when he needs it”? (1964, p. 381).

In the module outline, the framing over selection of problems for tutorials is very strong as the tutorial exercises from the textbook are pre-selected and cannot be changed. The regulative criteria is strongly framed in the module outline as it indicates that each tutorial session comprises four periods, two of which are compulsory (a register is taken). The additional tutorial problems had to be completed to the satisfaction of a tutor before students are allowed to sign out. To get a DP, students are required to attend 80% of tutorials and achieve 35% in all three tests. The dates, times and venues for the three tests are preset meaning that students have no voice in this decision. The module outline states that if students are unwell they should not write the test but must provide supporting evidence such as a doctor’s certificate to justify their absence.

To further examine the extent of classification and framing in the ME module I used lecture observations and interviews with lecturers to determine whether there was integration of content at the level of practice. During lecture observations, to determine whether interdisciplinary integration occurred I looked for any reference to application in other modules, verbal or demonstrated. Similarly reference to other sections or topics in the module served as evidence of the extent of intra-disciplinary relations and evidence of everyday examples were sought to confirm the degree of interdiscursive relations. A summary of the classification and framing that were evident in the ME module is presented using content and space as subheadings under classification and selection, sequencing, pacing and evaluative criteria as subheadings under framing. The analysis revealed very strong framing over selection, pacing and evaluative criteria. In all three cases the sequencing was strong because lecturers paused to answer students queries albeit without changing the sequence of topics covered in the lecture. A summary of the findings from analysis of data from observation of lectures and tutorials as well as interviews with academics is illustrated in, Table 6.6. The next section presents a description of the classification and framing within lecturers and tutorials.

Table 6.4

Summary of Classification and Framing of Lectures: Observation

	Lecturers	Dr A		DR B		Dr C	
Framing	Components	Lecture	Tutorial	Lectures	Tutorial	Lectures	Tutorial
	Selection of content/ problems	F++	F++	F++	F++	F++	F++
	Sequencing of content over semester	F++	F++	F++	F++	F++	F++
	Sequencing of content in lecture	F+	NA	F++	NA	F+	NA
	Sequencing of problems in lecture/ tutorial	F++	F--	F++	F--	F++	F--
	Pacing of content over semester	F++	F++	F++	F++	F++	F++
	Pacing of content in lecture/ tutorial	F++	F+	F++	F--	F++	F--
	Evaluative criteria within lectures/ tutorials	F++	F++	F++	F-	F++	F-
	Evaluative Criteria – students responses	F++	NA	F++	NA	F++	NA
	Evaluative Criteria – feedback on tests	F0		F0		F0	
Classification	Spaces (Inside/ outside)	C++	C++	C++	C-	C++	C-
	Spaces (Internal)	C+	C-	C+	C-	C++	C-
	Inter-disciplinary	C-	C++	C++	C++	C++	C++
	Intra-disciplinary	C+	C++	C++	C++	C++	C++
	Inter-discursive	C++	C++	C++	C++	C++	C+

6.6.2 Selection. The following statement captures the static nature of the current curriculum content for over two decades: “Ya so you just do the same every year and this is the syllabus, now off you go” (Interview, Dr B, 2012).

In general, neither students nor lecturers have a choice over the selection of content to be discussed in lectures as this is preselected and included in the module schedule. This was evident in the responses of lecturers during interviews. The schedule stipulates the sections to be completed by the end of each week. Consequently, the focus in this section will be on the selection of content and the problems presented in each lecture. In Dr A’s lectures, framing over the selection of content is very strong (F++) as given the constraint of the module schedule, he decides what sections and topics he will discuss for the day. The problems that Dr A uses in lectures to demonstrate the procedures involved in solving problems are selected by him making the framing over both the selection of content and problems very strong (F++). Similarly, DR B and Dr C select the content for the lecture as well as the problems that are discussed in lectures. So in general, observation of lectures in all three groups revealed very strong framing over selection of content for lectures.

In tutorials, the selection of tutorial exercises and additional tutorial problems for each tutorial session was very strongly framed in all of the tutorial sessions. Framing over selection of the tutorial exercises meant to prepare students for the weekly tutorial sessions was very strong as the problems were preselected by the module coordinator in agreement with the other two lecturers in the module and specified in the module outline. Similarly the selection of additional tutorial problems to be completed during the tutorials were very strongly framed in that, like the tutorial exercises, they were developed by the module coordinator giving students no input into this. Thus the selection of problems in preparation for each tutorial as well as for the actual tutorial were very strongly framed (F++). However within the tutorial session itself, what was consistent among all the tutorial sessions (the two compulsory periods) is that from the additional tutorial list allocated for the week students could select any problem(s) they required assistance with. Within the constraint of selecting from the additional tutorial list of problems, the selection of which problem(s) students wanted assistance with lay with them indicating a very weak framing in that aspect of selection (F--). This was consistent among all of the tutorials observed.

6.6.3 Sequencing. Sequencing of content refers to what comes before and what comes after. From the perspective of this study, sequencing was viewed in terms of whether the order of the topics followed the order of the module schedule. Student interjections were considered a deviation from the sequence if it was based on the topic at hand and was recorded as strong framing. Requests to discuss questions or sections not related to the day's lecture and which were accommodated were viewed as deviating substantially from the lesson and constituted weak framing. The sequencing of content in Dr A's lecture was strongly framed (F+). Dr A followed the sequence of topics as per the schedule and occasionally paused to answer students' questions. The questions, from my experience in the lectures were related to the topic at hand. Students did not often ask questions as the pace of the lesson was very fast but when they did he briefly 'told' them the correct answer and moved on with the lesson ensuring that the work scheduled to be completed for the day was accomplished. The questions that students raised generally pertained to the topic at hand. Within the lesson, he directed the sequence in which the content and problems were presented. The same observations were recorded for Dr C. He followed the order of topics as it appeared in the module schedule, seldom deviating from the sequence of the lecture unless a question related to the day's work was asked. The framing over sequencing of content was strong (F+). Dr B demonstrated very strong framing over sequencing. Interjections during lectures were few and far between. The topics were taught in the same sequence as that indicated in the module schedule. Students rarely asked questions but when they did Dr B demonstrated the problem again and quickly continued with the lesson. The module schedule was followed according to plan with minimal disruption to it characterizing the framing over selection as very strong (F++). In the lectures that I observed, I did not come across a situation where students requested a change of sequence.

Framing over sequencing in tutorials was analysed according to sequencing of weekly additional tutorials scheduled for the semester, those scheduled for the week and the sequence of the problems within the lecture. The sequencing of tutorial exercises and additional tutorials were very strongly framed. Specific tutorial exercises and additional tutorial problems were allocated to specific weeks of the semester. For example, problems from P1 (textbook) and Additional Tutorial 1 had to be done in the first tutorial of the semester. This was not negotiable reflecting a very strong framing over sequencing of topics over the semester (F++) as the order of the additional tutorials were not negotiable. However, students could decide the order of the problems within tutorials characterizing framing over sequencing as very weak (F--). This finding was consistent across all of the tutorial sessions.

6.6.4 Pacing. The pacing of lectures referred to the time frames that were involved in completing sections of work. In this study, strength of pacing was determined by matching the weekly time frames indicated in the module schedule against the time frames in which the content was covered in the same week. Dr A, Dr B and Dr C complete the content indicated on the weekly schedule as well as the work allocated for each lecture in the time frames indicated in the schedule. Hence pacing of content in lectures was very strong and consistent across all three lectures (F++). In lectures, questions were addressed very briefly by Dr A, who provided the correct answer, before continuing with the lecture. In Dr A's lectures the pacing of content was very strongly framed and very fast paced. Dr A. acknowledged the fast pace of lectures saying: "I'm going to go through this very quickly. You will be amazed at how fast I go through this". With all of the interjections, queries and requests, Dr A briefly addressed the issues then continued with the lesson ensuring that he adhered to the time frames stipulated on the schedule. Similarly Dr B and Dr C demonstrated very strong pacing

(F++) of content in lectures ensuring that the time frames according to the module schedule were strictly adhered to.

Framing over pacing of tutorials was judged across the semester and within the tutorial. While framing over pacing of content across the weeks was very strong (F++), framing over pacing within the lecture differed across the tutorials supervised by different lecturers. In Dr A's tutorials, the pacing of content was very strong (F++) as while students could work at their own pace, they were required to complete the work within the tutorial session and to the satisfaction of the tutor. In tutorials supervised by Dr B, despite the rules stating that students could only sign off register once they had completed the work to the satisfaction of the lecturer, students could sign and leave after about 20 minutes of the tutorial without completing their work. Tutors seemed reluctant to monitor students' work to check whether it was done correctly. Considering the evidence, pacing in Dr B's tutorials was very weakly framed (F--). In Dr C's tutorial sessions, pacing was very weakly framed since the rules were a bit more relaxed and contrary to the tutorials of other lecturers, as the solutions were projected onto the screen at the beginning of the tutorial. This meant that students had access to the solutions very early in the tutorial session. For the other tutorial groups the tutorial solutions were uploaded onto the learning@sahei website at the end of the week. If the tutor was strict in that session, then the register was signed later rather than sooner otherwise students were allowed to sign and leave at will.

6.6.5 Evaluative criteria. One of the guiding principles of the Teaching, Learning and Assessment policy at the SAHEI suggest that assessments be an "integral part of the teaching and learning cycle and enhances engagement with the learning task and self–assessment" (SAHEI, 2008). This statement suggests that there should be student participation in assessment which is reflective of weaker framing over the evaluative criteria. This was not the case in this ME module.

To determine framing over the evaluative criteria, I looked at whether lecturers made explicit what students needed to know and to be able to do. In other words was the legitimate text explicated? I also evaluated this based on feedback from lecturers. This refers to the extent of lecturer's response to students' questions and opportunities for students to respond to lecturers questions. The framing over evaluative criteria was very strong in all three groups of lectures observed. During the lecture Dr A, Dr B and Dr C explicitly defined and explained the concepts, addressed key aspects of the content that would be tested, provided typical test questions as well as step-by-step instructions on how to solve them. Lecturers informed students which formulae, rules and definitions they needed to know and how they were to be used. For example:

> A typical question you'll see in your first test is this one … so take note of this question here in purple [points to the purple question projected from the Thinkpad onto the board] … express the given repeating decimal as a quotient of integers and its 3.27 … what would that mean? (Lecture observation, Dr A, 2012)

In Dr A's lectures framing over evaluative criteria regarding the content in lectures was very strong (F++). Dr A wrote little comments on his lecture notes reminding students what was important and what to look out for. Lecture notes were then uploaded onto the website which all students registered in the module had access to. Dr A often directed questions to students and immediately answered them himself without waiting for or exploring their responses. In that regard evaluative criteria were not explicit as students were not given the opportunity to clarify what they know and do not know. Dr B was explicit about the evaluative criteria (F++) in her lectures:

> the real numbers the important thing and … I'm sure your first question in your additional tut and probably the first question in your test will be to show that some number is a rational number … and we did some examples and those will be on the website so you can see. (Lecture observation, Dr B, 2012)

In Dr C's lectures the evaluative criteria are made explicit (F++). He told students what to learn and how to learn. He indicated what must be rote learned and what must be practiced as exemplified in the following statement: "Unfortunately the only way to learn is to by-heart it and practice". (Lecture observation, Dr C, 2012)

In Dr A's lectures, student responses to his questions were not explored, but the correct solution was provided. Responses to students' queries were clear in terms of what they would be expected to produce in assessments. As such framing over evaluative criteria based on feedback to students was explicit (F++). In addition Dr B neither encouraged students to ask questions nor asked questions of students. However when students did (seldom) ask questions, she responded patiently, clarifying their queries. Considering how seldom clarifications were requested it is difficult to classify the evaluative criteria with regard to responses as strong or weak. However Dr B did respond patiently whenever queries were put to him and I will thus regard this as strong framing over evaluative criteria. Dr B offered clear explanations to students' queries which made the evaluative criteria clear (F+). Dr C ensured that he provided feedback which clarified the expectation of the lecturers in assessments (F++).

Framing of evaluative criteria was very strong in Dr A's tutorials (F++). When students called for assistance, tutors mostly wrote out the entire solution in their work books, explained the procedure step by step and were told what to focus on. In Dr B's tutorial sessions it was difficult to determine the extent of framing over the evaluative criteria. Often the tutors in this group demonstrated their own methods of solving the problem which were not the general methods used by the lecturers. Hence the evaluative criteria were not made very explicit. As such in Dr B's tutorials, framing over evaluative criteria was weak (F-). From my observation of Dr C's tutorials, contrary to what transpired in the tutorials of the other two lecturers, solutions were put up at the beginning of the tutorial. Students spend their time trying to figure out how get to the answer. While the solutions were provided, many steps were missing in the solution and students complained of illegible handwriting. This indicates weak framing over evaluative criteria in tutorials (F-).

Feedback: Tests were marked by tutors and not the lecturers, but in accordance with the marking memorandum provided by Dr C. Framing over evaluative criteria with respect to marking and correction of tests was weak. The only indication of the student's performance was a tick or cross indicating that the solution was correct or incorrect. There were no indications on test scripts of what was missing in the solutions or what the correct solutions were. The solutions were put up on the course website after the marks were released. Students had recourse to consult with lecturers and query their marks once they picked up their scripts. So the students had access to the correct solutions, were able to self-evaluate thereby increasing their opportunity to produce the legitimate text in the future. However all of this is dependent on student agency as if students neither picked up their scripts nor queried with lecturers, there was little opportunity to explicate the legitimate text. Feedback was not provided on an individual level although it was provided generally to all students.

The marking of tests was done by tutors who did not provide feedback on tests scripts. This indicated weak framing of the evaluative criteria as students were not clear on why their solutions were incorrect. According to Dr C, if students were unhappy with the marking their recourse was to take up queries with the lecturer who would resolve the issue: “if [students] are unhappy with the mark, they'll come to see us”. There were mixed responses regarding the quality of marking. Dr C was quite satisfied with the quality of marking provided by the tutors and said:

> I give [tutors] model answers, … all possible combinations ... and say if they are unsure about anything, they must phone me or e-mail me . But... I tend to trust them ... if I have too many coming to see me then I know that there's a serious problem ... there's been very few changes, so the marking was done well. (Lecturer interview, Dr C, 2012)

However Dr B felt that test marking was not done carefully:

> They [students] are so weak honestly and then the markers, the marking is also bad. Ya but we can't mark three tests and the exams ... so they have a model answer and they can phone us at any point in time if they're not sure. (Lecturer interview, Dr B, 2012)

Ultimately the interviews revealed consensus amongst all three lecturers who acknowledged that doing the additional tutorials counted as one of the reasons why students were successful in the module.

My observation of all three lectures yielded no evidence of students selecting problems that are used in solving problems. The selection content was very strongly framed and was evidenced during observation of lectures where the content that each of the lecturers presented for the week was matched against the module outline and revealed it was as per the module schedule. The predominantly strong framing of selection, sequencing, pacing and evaluative criteria in lectures, facilitated progress in the lectures, enabled all three groups to progress at a similar pace and made it possible for each group to complete the sections needed to participate constructively in tutorials and tests. However the structure of the module is not the only factor influencing teaching and learning as will be shown in Chapter Seven and on its own can therefore not fully explain student performance.

6.6.6 Student questionnaire. To ascertain students' perceptions of the classification of content on an interdisciplinary level, I included the following question on the student questionnaire: *Was the content covered in the Math 131 module useful in other modules that you have done?* Data from student responses to the question were used to determine the classification of content in other concurrent modules that they were registered for. A frequency count was done on the questionnaire data. Of the responses, 79% of the students indicated that it was useful, while 11% considered it not useful in other subjects. 10% of the students did not respond to this question. Of the 79% (220 students) who felt the ME module was useful in other disciplines, 73% (160 students) noted that it was useful in Physics. Of the total number of students who perceived the ME module to be useful in other disciplines, 8% indicated that it was useful in Chemistry and Chemistry-related modules. While students made the connection between the Mathematics presented in the ME module predominantly to Physics, the data at this level of the analysis could not show that the connection between mathematics and physics and chemistry were due to the interdisciplinary relations demonstrated during lectures in the ME module, (due to the manner in which it was taught), that is whether examples of application and relevance in other disciplines were discussed during lectures, whether students themselves made the connection or whether this connection was achieved in the Physics and Chemistry lectures. Neither the Physics nor the Chemistry modules were under scrutiny, thus making their appraisal beyond the scope of this study. As such with the given data it was not possible to determine whether the relevance and application of the mathematics in the ME module was made known in the teaching and learning of the ME module.

6.7 Conclusion

In this chapter the classification and framing of the ME module was presented. To determine the strength of classification of the contents of the ME module, an analysis of the strength of insulation between categories was conducted. The analysis focused on the strength of insulation of the content between mathematics and other subjects (interdisciplinary), between different topics within the module (intradisciplinary) and between mathematics and everyday knowledge (interdiscursive). The module under scrutiny was found to be very strongly classified on the inter-disciplinary, intra-disciplinary and inter-discursive levels. Data from observation of lectures and tutorials and interviews with lecturers were used to describe the framing of the pedagogy among three lecture groups. The findings across all three groups showed many similarities and slight differences in the framing and classification. The classification and framing describe different modalities of pedagogic practice that arose out of different strengths of framing evident in sequencing, pacing and evaluative criteria. A discussion of the data ensues in Chapter Eight. Chapter Seven presents the themes which emerged from the data and is discussed in terms of the actual practice of teachers in lectures and tutorials. The data is presented as three case studies embedded within the larger case of the ME module.

Chapter Seven
Teaching and Learning

Merriam describes the case study as "an intensive description and analysis of a phenomenon", which "seeks to describe the phenomenon in depth" (Merriam, 2002, p. 8). To gain an in depth description of teaching and learning in the ME module I analysed the module on two levels. First the structure of the three message systems was analysed using Bernstein's concepts of classification and framing as a framework, the findings of which were presented in Chapter Six. Second, using preset categories from the beliefs framework, Bloom's revised taxonomy and themes that emerged from the data this chapter provides a detailed description and analysis of how and why teaching and learning is approached the way it is in each lecture group. These are presented as three case studies in this chapter. This chapter begins with an exposition of the case studies which reports on the findings of observations, interviews and the questionnaire under the following subheadings: How is teaching and learning approached? and Why is teaching and learning approached in the ways that they are? For each lecturer a description of teaching styles and beliefs is presented. Following the case studies the findings from the analysis of module assessments using Bloom's revised taxonomy as a framework is presented. This chapter concludes with a summary of the findings.

7.1 Review of Previous Chapters

As reported previously the approach of this study is pragmatic; the research questions are considered central to data collection and thus methods most appropriate to generate the data to answer the research questions were used. The process of data collection and analysis reflect my ontological and epistemological stance. Four lectures were observed in each of the different lecture groups in the ME module and the data were used in the analysis. In addition, interviews were held with lecturers and students as, ontologically, in keeping with the pragmatic approach, I acknowledge that there are multiple realities and that there could be differences in what lecturers were saying (espoused beliefs) and doing (enacted beliefs). The citation repeated below is to remind the reader why research into teaching and learning is considered important:

> At the heart of the educational process lies the curriculum and the crucial question, "'What should we each?' Whatever we intend to do with education, or believe is happening because of it, occurs by virtue of the transmission of knowledge intended to transform the learner" (Moore, 2004, p. 147).

Data from the first phase of the analysis using Bernstein's concepts of classification and framing as a framework was presented. Next the findings of the analysis of data using personal theories and beliefs and Bloom's revised taxonomy are discussed. In establishing the teaching style of lecturers I drew on the summary of personal theories and beliefs discussed in Chapter Three which is re-iterated here. The characteristics of the teaching styles are summarised in Table 7.1. Absolutist teaching is evidenced in behavior where the teacher is the authority and source of knowledge, encourages students to follow rules and procedures to get to the single, correct answer. Formalist teaching is distinguished when the teacher emphasises the underlying logical structure of mathematics and formal geometric proofs.

Table 7.1

Summary of Teaching Styles

Absolutist	Formalist
Teacher is the authority and source of mathematical truth	Teacher takes pains to demonstrate the underlying logical structure of mathematics
Following rules and procedures leads to the correct answer	Emphasise formal geometric proofs
Work toward a single correct answer	

Instrumentalist/ algorithmic	Fallibilist/ social constructivist
Emphasises teacher as authority, taking down notes	Encourages students to question and think
Teaching rules without explanation	Encourages students to participate in their own learning
Demonstrates procedures that students must use	Effort to build student understanding
Encourages students to memorise and practice procedures and computation	Encourage students to make conjectures and reason out solutions to problems

Fallibilist teaching is evident in teacher behavior which encourages students to question, to think, to participate in their own learning, makes an effort to build student understanding and encourages students to make conjectures and work out solutions to problems. The instrumentalist/ algorithmic teacher demonstrates the following behaviour: the teacher is seen as the authority, note-taking, teaching rules without explanation, demonstrates procedures that students must use and encourages students to memorise and practice procedures and computation. This excerpt from the interview transcript captures the essence of how teaching and learning is approached at the SAHEI:

> It's a very algorithmic approach. You see a question, you follow these steps, you will get the answer. It's like baking a cake. Here's the recipe, here's the ingredients, switch the stove on, you'll get a cake in the end. The approach [is] … not for engineering students. (Interview, Dr A, 2012)

The three case studies below provide a full, rich description of teaching and learning in the ME module. Across the many lectures that I observed, generally the format was very similar. Therefore for each case study, an exposition of one lecture is presented as it indicates what happened in the rest of the lectures that I observed.

7.2 Case Study 1: Dr A, Lecturer in the ME Module, (Group A).

Dr A is a Physicist with a doctoral degree in Astrophysics. He has been a lecturer in mathematics at the SAHEI for 22 years and has thus had much experience lecturing mathematics to engineering students. Dr A prides himself on being a physicist and not a mathematician, a claim he made constantly during the mathematics lecture: “I’m a physicist, not a mathematician”. Dr A has an open-door policy and accommodated consultation with students whenever he was not lecturing. The year this study was conducted Dr A was allocated lecture group A, comprising 221 students.

7.2.1 Dr A’s teaching style. The goal of the lecture seemed to be to complete the amount of work scheduled for the lecture. The lecture generally began with a brief summary of what transpired in the previous lecture. Dr A asked students whether they had any questions regarding the work presented in the previous lecture and then proceeded to briefly respond to the queries if there were any. He then began the lecture with a brief explanation of what he was going to teach in that lecture and continued with the lesson. He often directed questions to students but they seemed to be rhetorical as he seldom gave them the opportunity to respond individually. This was evident in the chorus of responses which were seldom explored as Dr A almost immediately answered his own question and continued with the lecture. The pacing of the lecture was very fast and Dr A advised students to listen to the lecture and download the lecture notes which he faithfully uploaded after every lecture. The lecture continued in that way until Dr A had completed the work that he had scheduled for the day. He ended every lecture asking students whether they had any questions and left them with a reminder of what would be covered in the next lecture.

Dr A spent a large part of the lecture explaining what students needed to do to pass the module. He demonstrated strong framing over hierarchical rules and was authoritative in his approach. For example, he told the students that there were, "lot's of rules! ... I will walk out of my lecture and if I find you outside when you're supposed to be inside, you're going to be in trouble". He emphasised that the key to passing this course was "doing your tutorials, right?" (Lecture observation, Dr A, 2012). For the benefit of students Dr A set up housekeeping rules including averaging at least 50% in their semester tests, and attending 100% of the tutorials and emphasised "this is my class I make the rules." From the lectures observed which were used in the analysis it was apparent that Dr A's goals were focused on getting students to pass the module: "I just want to give you a brief overview of … what I expect of you and … [if you] listen to me … you'll pass and if you don't you'll fail." While he was vociferous about the consequences of students not following his advice, he attempted to motivate them by suggesting "I'm thinking this year we'll get 100% pass rate. What do you think?" [There are murmurings of yes from the students]… "if you people work very hard together." His words suggest that his intention was to get all students to pass the ME module.

When asked: 'Do you think this module is exam-orientated, exam-driven?', Dr A responded: "It has to be unfortunately" (Interview, Dr A, 2012). The assessment orientated approach was consistent throughout the semester and was evident in the several references that he made to problems that he was demonstrating: "this is a typical test or exam question!" The focus on assessment was consistent across all four lectures that I observed: In addition, while Dr A attempted to relate the mathematics to real-life applications in his lectures, he still adopted an algorithmic approach. This is evident in the following excerpt which captures Dr A reciting the rule: "Do it step-by-step … wherever there is **f** put a square root [and so the lesson continued]". His approach to solving the problem was evidently algorithmic as he emphasized the step-by-step procedure in solving the problem:

> Now I want you to write **cos 2θ** in terms of **sin θ** … absolutely important! Which formula do you use first one or second one? [students shout out different answers in chorus] … So go on the other side wherever there is an '**a**' put **β**. Wherever there is a '**b**' put **θ** … everyone happy with that? (Lecture observation, Dr A, 2012)

The statement: "They not going to ask you to prove it, they are going to ask you to use it … you must know this", suggests that students had to 'know' the rules, formulae and definitions. I surmised that 'knowing' the rules implies memorizing them as students were not exposed to the theoretical underpinnings of the rules. Dr A indicated in the interview that having a good lecture was "awesome … It's very important to me to feel satisfied with what I have done" and that if someone indicated they did not like the way he approached the lesson he would "find a better way".

Ultimately the tutorials were exam-driven as the focus was the additional tutorial problems, a point emphasized by Dr A: "we want everyone working on the additional tut as that's the one that's important". I can infer that they were important for the assessments. The general format of Dr A's tutorials was as follows. Dr A and all four tutors were present, punctual and seemed prepared (I observed them as they were assisting students). One of the tutors was allocated the responsibility of monitoring the register and checking that students had completed the additional tutorial sufficiently well before allowing them to sign and leave. Tutors and the lecturer walked around the venue assisting students when they requested help and otherwise. Few students got away with doing nothing as they were all well-monitored. The tutorials were well-organised, with students generally knowing the rules of the tutorial, what to do and who to go to for help. Students worked in different ways in the tutorials, independently at times and with their peers at other times.

Drawing on the table of criteria presented in Chapter Two, Dr A demonstrated an assessment-driven and algorithmic approach to teaching as he emphasised using the lecture notes, typical test problems, step-by-step procedures, rules and rote learning, which are characteristic of an algorithmic approach. The perception created was one of teacher as authority. The rationale he provided for his teaching decisions is discussed in the next section.

7.2.2 Dr A's rationale for teaching. An indication of Dr A's rationale was determined from interview data and observations. Dr A noted that his goal in the ME module was to teach students the basics:

> The first thing would be the most fundamental is to teach some of the basics … and the second part is the application which by the way is not emphasized in this course … That's my approach [as] I look at examples in the real world and then I try to relate specific sections to those real examples. (Interview, Dr A, 2012)

I inferred from Dr A's interview that he views mathematics as language and a human activity: "If they [students] can recognise all these mathematicians who contributed to this, are human beings just like us, they will appreciate the subject." Dr A distinguished between pure mathematics and applied mathematics for engineers, indicating that there was a big difference between the two and that this required different approaches to teaching. This was exemplified by the excerpt from the interview transcript: "My definition of … pure mathematics it is really a language which is used in the applied sciences for example, physics, biology, engineering … In applied mathematics it is giving physical interpretation to it. Big difference!" (Lecturer interview, Dr A, 2012). He indicated that he taught mathematics as though it was an Applied Mathematics module suggesting that his intention was to develop problem solving skills. However, students were rarely provided with the opportunity to engage in problem solving during lectures and in tutorials, problem solving strategies were not specifically taught. In tutorials the focus was on using the lecture examples to solve the additional tutorial problems.

His belief is that anyone can solve mathematical problems given the time but that the interpretation of that solution with regard to what it was describing was of greater value and rarely accomplished: "problem solving with the intention of describing reality … you give … a problem to a person … given enough time anyone can find that solution. What is that solution telling us, what is it describing?" When asked in the interview whether all students were capable of doing mathematics, Dr A indicated his belief that given sufficient time anyone could acquire the knowledge and were thus capable of learning mathematics: "I mean we can all do maths ... given enough time you can acquire that knowledge.” Furthermore, he asserted that the students’ intentions in the module were important as: “The problem here … [is] the intention of the students is to pass maths. That’s the problem, not to learn mathematics. This is a big difference” (Lecturer interview, Dr A, 2012).

Dr A indicated that because the intention was to ensure that students passed the ME module the approach commonly adopted to teaching and learning in this module was to provide opportunity for practicing examples and not necessarily to develop understanding: “You see so … the most common approach to this course is … we give enough examples … for example textbook examples, tutorial examples and you'll pass. The problem, I'll emphasise this it doesn't mean you understand the mathematics”. Dr A indicated that teaching students sections that they were expected to have completed in high school but did not, took up a lot of time, time that he could “have used to teach differently … also show applications. I don't have time for that now ... I just go through the fundamentals.”

Dr A often made attempts in lecturers to show the relevance of mathematics to other disciplines. For example, in the section on Combination of Functions, Dr A began his lecture by focusing on the combination of functions to generate new functions using the four basic operations (sum, difference, quotient and product). He used examples based on the topic to illustrate the application of this section to those in Physical Science (semi-conductors and electrons). In addition, in the interview, his response to my question asking where mathematics was relevant in other engineering modules, indicated that he had a good understanding of other discourses that it was useful in, “Mechanics … in Applied Maths, … [and] Physics. That's how fundamental this subject is.”

Dr A indicated that some of the challenges in the mathematics class were, “just their inability to understand mathematics ... It's all about their knowledge base.” Dr A was aware that students lacked fundamental mathematical knowledge from high school. Time was thus spent teaching the ‘fundamentals’ which he felt were crucial to students’ understanding of the module content at the expense of teaching with applications. He stated, “right now you know, I'm teaching logarithms. They've never seen it, so they’re going to take twice as much time to understand it”. In the interview, Dr A also described the mathematics students in his class as dependent and lacking confidence: “You ask them to solve a problem they need to go and ask the person next to them. No confidence”. He claimed that the reason for poor performance amongst first year students in the ME module was because they could not think creatively or "out of the box." His perception was that students' approach to learning was algorithmic and that they could not do anything beyond following procedures. This, he claims, was because of a recipe-style of teaching, that he termed the "solve for x syndrome." He indicated that students could not see the link between mathematics and physics and found it difficult to extract the data in the problem.

7.3 Case Study 2: Dr B, Lecturer in the ME Module, (Group B).

Dr B has a doctoral degree in Mathematics and has three years of experience lecturing in the ME module. He does not have set consultation times but prefers to use the 10 minute break between the double lectures once a week to take students queries. Dr B was allocated a total of 200 students in his group, Group B.

Dr B generally began the lecture with a short recap of the previous one and then moved on with the day's work. He wrote the solutions to problems on a transparency as he talked through the solution with students (these notes are uploaded onto the website). He rarely directed questions to students and students seldom asked questions but when they did Dr B accommodated them by working out the problem again and quickly resumed the lesson. He constantly emphasized what had to be learned, and how it was to be learned. There did not seem to be much order as students walked in late and left early and were consistently rowdy during the lecture despite the lecturer constantly requesting them to be quiet. Despite the distractions, the work that was scheduled for the lesson was completed by the end of the lecture.

Dr B emphasized the importance of attending the tutorials and doing the tutorial problems:

> the most important thing about the tut, … you must sit and work through them … Don't sit and talk and … you can have a break and go outside but do the tuts in your tut. Don't fall behind. Because a lot of the tests and exam questions are based on those additional tuts so you must do them. (Lecture observation, Dr B, 2012)

Students were also encouraged to use the website and to rather listen, “get it in your heads, understand it, maybe write a few of the examples down, if you like”. However, tutorials under Dr B’s supervision were not very well organised as tutors were not punctual and many did not present themselves at all. Lack of sufficient tutors contributed to the chaos in tutorials. This combined with the small tutorial venues made it difficult to manage the register properly and monitor student attendance. These tutorials were conducted in a vastly different manner than those supervised by Dr A.

7.3.1 Dr B’s teaching style. The following extracts from the lecture observations have been documented to illustrate several references were made indicating that lectures were assessment-orientated: “easy marks! ... I guarantee, if you are asked … to find the equation of the inverse … you will be able to solve” and they [examiners] “will always be asking it of you at a particular point … always! Take this to your tut next week” [refers to the rules given] … “they all exactly the same.” Dr B showed students strategies to pass as exemplified in the following segments showing students how to ‘figure out’ the correct method:

> These two methods, it seems like getting the derivative is the easier one so go for that first and if that’s not working out you must use that $f(x_1)$ equals $f(x_2)$ … You must just remember … the steps that I did. (Observation, Dr B, 2012)

He focused on ways to maximize their marks even if they used the incorrect equation:

> Incidentally … if you didn’t get minus eleven so now this equation here is wrong [referring to the equation on the board] we are not going to mark the rest of it wrong, … we will mark the method … based on your wrong equation … take the wrong equation and work out everything according to the wrong equation … in fact you can get all your answers wrong … [and] arithmetically get 90%. (Observation, Dr B, 2012)

Dr B demonstrated an instrumental approach to teaching and learning. During observations of his lectures, it was evident that the approach used was to ‘solve problems’ step-by-step’. This was consistent in all of the lectures observed. This is exemplified in the following example as written on the board:

1. If *f* is increasing and *f* is 1:1 then it has an inverse.
2. *f(g) = x*

So if **f(x) = 2x – 1**

Then **f(g) = 2y – 1**

2y – 1 = x

2y = x + 1

y = ½ (x + 1) = equation of inverse

(Observation, Dr B, 2012)

He also encouraged the students to rote learn: “you must know all these cases off by heart”. Memorisation of rules was emphasized constantly in lectures: “**y = dx/dy** not **dy/dx** … that’s what I want you to remember”. When asked whether he reflected on his teaching, Dr B responded: “Yes I do … some lectures you just have a brilliant lecture and … the students are with you and then other times you … know, something … didn't click or gel. I didn't quite do it”. He added “I'll explain something in a different way if I can see I've lost them”.

In my observation of Dr B’s lectures, there was no demonstration or explanation of how mathematics was relevant in other engineering modules. In the interview, when asked about the role and relevance of mathematics in engineering, Dr B’s response suggested a lack of knowledge about the relevance of the mathematics and its usefulness in other modules and contexts. This is supported by the statement: “I think they use it in Physics, a lot, chemistry as well I think. I think most of the engineering somewhere they have to use maths”. In addition Dr B commented that he was not able to show the relevance of mathematics in other contexts as time did not permit.

Dr B encouraged note taking, memorising rules, formulae, definitions and procedures without providing explanations for why the rules worked the way they did. He stressed step-by-step procedures that students were expected to follow and showed them strategies to ‘figure out’ which formula to use and how to maximise method marks. The observed teaching behaviour according to the criteria evidenced algorithmic teaching. Dr B’s rationale for his teaching decisions is discussed in the next section.

7.3.2 Dr B's rationale for teaching. An indication of Dr B's rationale was determined from interview data and observations. Dr B stated that his goal in the mathematics class was to teach students "just so that they basically understand the math, there's no time to show them how they actually get to use this in" the real world and "maybe to enjoy it a little bit at the end of the day." The goal of getting students to pass the ME module was contradicted in Dr B's statement during a lecture when he encouraged students to learn the method rather than understand the mathematics:

> so it's all your method … in fact you can get all your answers wrong … [and] arithmetically get 90% … we are going to use that property [referring to the property written on the board] … so you must just learn that off by heart … got to know this one. (Lecture observation, Dr B, 2012)

This was contrary to what Dr B indicated in the interview when he said that his goal in the mathematics lectures was for students to understand the mathematics. Dr B stated that mathematics in the context of engineering was "a tool for them to solve their problems; they need to use it, to use it as a tool." The approach to teaching and learning reflected in lectures was consistent with the notion of mathematics as a 'toolbox' indicated during the interview. He indicated that students could not learn deductively as they would not be able to understand the mathematics had he presented the theory first. This is evident in the following excerpt from the interview transcript: "Although if I did the theory first … you would not have understood." He indicated that not all students are capable of doing mathematics as he felt, "they have all got their limits" as their mathematics ability is innate and thus static. This implies that students can do mathematics to a certain level and not beyond: "I think underlying it, everybody has got a certain limit and how well you do … I'd say everyone's got their ... it's just that ... how you're made." Dr B's description of what constitutes doing mathematics is captured in the following statement: "When they sitting, writing it down for themselves, when they are solving a problem … not when they are listening … to the answer, or watching me write the answer down". While Dr B indicated that students needed to be actively involved to be doing mathematics, my observation revealed that lectures afforded little or no opportunity for students to engage in doing mathematics the way he described it should be done whereas in tutorials, students were left very much to their own devices.

In response to how he went about teaching, Dr B said, “we just follow the book, get to the end of every week what [point] you got to get up to, then we just GO”. This indicates that teaching and learning was driven by the module schedule (‘book’) and that lecturers themselves were governed by strong framing over selection, sequencing and pacing regarding the content that needed to be completed, the order in which it had to be completed and the time frames in which they had to be done. During one of the lessons Dr B indicated that he used methods that he had been taught at school and was using in ME lectures to demonstrate to students how to solve the problem: “I did one way at school but if you were taught a different way it is absolutely fine”.

Dr B indicated that lack of mathematical competencies that students should have acquired at high school was a barrier to progress in lectures:

> It's actually the basics that they come and ask you that they shouldn’t be asking you … and it takes time, because you just want to do the course work and you got to now try and teach them something they should have done at school. (Lecture observation, Dr B, 2012)

When asked whether student’s lack of basic mathematical knowledge could be addressed in tutorials, Dr B responded positively stating, “ya, you do spend quite a bit of time in the tuts but then you've got other ones waiting [students requiring assistance with the ME module]”. He explained that students failed because they did not make an effort and were also, “not very diligent as they don't work … we are here to help them, they waste the time … most of them just sit back and you know we must do all the work for them”. He indicated that improvement depended on the student’s desire to enhance their learning: “If they wanted to get up to standard you know they would” (Lecturer interview, Dr B, 2012).

Furthermore, Dr B noted that students were rowdy during lectures and that it was distracting and time-consuming to constantly remind them to be quiet:

> They like to talk all time… I mean I try to tell them to keep quiet for the ones that want to learn, but sometimes I get quite cross and I really shout but then you waste half your lecture telling them to keep quiet. (Lecturer interview, Dr B, 2012)

This could explain why he chose to ignore the rowdiness. It also provided a reason for why he spent most of his time looking down at the transparency and mostly not at the students, choosing rather to ignore the noise and 'forge on' with the lesson.

7.4 Case Study 3: Dr C, Lecturer in the ME Module, (Group C).

Dr C has undergraduate and postgraduate qualifications in mathematics and a doctorate in higher education. His experience teaching mathematics to engineering students spans more than 20 years. He is also the module coordinator and is thus responsible for drawing up the tutorials, additional tutorials, mock tests and tests, mock examinations and examinations. For the tests and examinations he draws up the questions, circulates to all lecturers involved in the module and incorporates their feedback into the assessments. Theoretically all lecturers have the opportunity to make input into the tests and examinations and to ensure the fairness and quality of the paper. Dr C stipulated his consultation hours and insisted that students show him their attempt at solving the problems to facilitate assisting them. In semester 1, Dr C lectured mathematics to 200 engineering students.

7.4.1 Dr C's teaching style. Dr C's teaching style appears to be a combination of assessment-oriented, instrumental and trying to develop understanding and reasoning, despite stating in the interview that: "the problem with students is that they want to understand and I say the simplest, you can't understand". From observation, it was evident that Dr C's style of lecturing was that of 'telling' students what to do step-by-step, reinforcing procedures and asking questions that expect students to 'fill in the blanks', in chorus. Students were told consistently that they had to rote learn the formulae, rules and definitions and that they had to practice examination-type problems: "they have to learn the definitions, off by heart, … and then they've just got to practice the … typical types of problems that they can expect in a test and exams" (Interview, Dr C, 2012). Evidence shows that Dr C encouraged students to learn rules and definitions off by heart:

> so these you must know off by heart … all you have to do is read and learn everything and … this is a standard mathematical definition, god-given thing … so these things you going to have to learn off by heart. (Observation, Dr C, 2012)

There were several references to ‘typical test problems’ as exemplified in the following extracts that were selected for transcription over the four days of observations: “Yes the typical problem that you going to get” [in test and examination]. While he used the opportunity to clarify and explain concepts to students as well as to give them insight into the purpose of concepts, as with the other lecturers, he showed students how to solve problems using step-by-step procedures illustrated in the following segment:

> Absolute takes away any negative value of …**y**… if I can give you any standard graph and I put the strokes on either side, how you going to sketch it? Take the strokes away, sketch the ordinary graph and since all the **y**-values must be positive, so any negative **y’s** what will you do? Flip them [answers own question]. If the graph doesn’t go below the x-axis, then it’ the same but if it does then we have to flip them. So this is the graph **y = |x|**. … we get two cases. When it’s positive, we drop them when it’s negative we put a minus. Graphically drop those things [draws strokes] sketch that graph for me, then any negative ones, flip … sketch y = x first [draws this part of the graph] then flip all the negative values up [indicates flip about the axis]. (Interview, Dr C, 2012)

Dr C was open to sharing ideas with other lecturers but was not convinced that different methods demonstrated by others would work. He acknowledged that there probably were other ways of teaching certain sections and that he would use them if it could be shown that they were effective in enhancing students’ understanding.

There were clear indications that Dr C’s approach to teaching was algorithmic as he demonstrated criteria that were characteristic of algorithmic teaching as indicated in Table 7.1. He distinctly told students to take down notes, and got them to recite the steps of the problem as he wrote them down. Students were told to *by-heart* rules, formulae and definitions. Dr C showed students how to use step-by-step procedures to solve problems and told them to practice examination type problems following the same steps which appeared in the additional tutorials and mock assessments. Dr C’s rationale for his teaching decision is discussed in section 7.4.2

7.4.2 Dr C’s rationale for teaching. Insight into Dr C’s rationale for his teaching approach was determined from interview data and observations. Dr C’s goal in the ME module was to ensure that firstly students knew they had to memorise definitions, rules and formulae and secondly to practice: “Number one, I want the students to know that they have to learn things off by heart”. Secondly, he wanted them to, “practice and that is the main thing I'm trying to get across to them”. Thirdly he indicated that students needed to be provided with, “the things that they need to learn off by heart, and finally they had to have the right materials and learning goals. But they have to work, know that they must work so that's the goal”! When asked how he would define mathematics, Dr C found it difficult to pin down a specific definition and responded that:

> There isn't a defined definition. There’s so many branches … You can't just say maths is this. Okay I think perhaps one could say that maths is used to deal with problems that happen in the world, if something happens you can try to solve the problem. (Interview, Dr C, 2012)

He eventually decided that mathematics is used to deal with problems in the world. He distinguished between doing mathematics as an undergraduate student and as a researcher. To Dr C doing mathematics as an undergraduate student meant, “solving maths problems. Well depends if doing maths of existing maths problems”, implying problems ‘seen’ before, while doing mathematics as a researcher meant “creating theories or theorems or proving unsolved problems … creating new problems”.

He acknowledged that he did not show the relevance of mathematics to other engineering modules and indicated because, “to try and connect it to the other fields it's going to take more time. We don't have, we’ve got so much to cover in the syllabus”, because, “they're so overloaded in first year … it is difficult for them to connect it to other subjects”. Dr C indicated that mathematics had applications in chemistry and physics but that due to the time constraints, it was not possible to link it to those modules. However he did acknowledge the implications of not showing applications in engineering as, “it's only when you get further on that you start realising the implications”.

Dr C’s response about students’ ability to do mathematics yielded mixed views on this question. On the one hand he stated that every student had the capability to do mathematics. In response to the question: Are all students capable of doing mathematics?, Dr C’s response was:

> Definitely not. No. Of course not. … for a person to do undergraduate maths I think generally most people can … but to go beyond that …I don't think everybody can … if there's no time limit then everybody can most probably do it, under the time constraints they can't. (Interview, Dr C, 2012)

In response to the question asking why students failed, Dr C indicated “I think that it might be that they [students] are just lazy” and that they neither learned definitions off by heart nor practiced the problems given to them indicating that there were fixed mechanical steps that students had to follow to solve problems.

When asked how students should go about learning in the mathematics module, Dr C responded that they had to rote-learn and practice typical tests and examination problems. He responded:

> Like I said, first they have to learn the definitions, off by heart they got to know things off by heart, … then they have to know the steps off by heart … and then they've just got to practice … typical types of problems that they can expect in a test and exams. (Interview, Dr C, 2012)

He encouraged memorization as he believed that would enable students to follow the step-by-step procedures exactly and improve students’ competency in problem solving. Dr C commented that the consequence of not memorizing rules and practicing problems were students who ‘waffle’ through the mathematics. He also indicated that, “it was not possible for students to understand because it's taken hundreds of years to evolve you just got to apply the stuff, understanding sometimes comes years later when you mature.”

He asserted that the additional tutorial problems were typical problems demonstrated in lectures and set in the tutorials which he encouraged them to learn off by heart. He explained that if students memorised the steps involved in solving problems, practiced and revised lecture notes and did this immediately, there was a 90% chance of memory retention. He indicated that from his experience of lecturing the module previously he was able to acknowledge aspects of the module that students generally had difficulty with and the common misconceptions that students have and was thus able to advise them accordingly in lectures. Dr C indicated that while he attempted to find and use new methods of teaching the different mathematics topics, he also tried to determine whether the methods used made a difference to the students: “There was one thing like the absolute value … somebody else showed me, explained it this way and it made a difference.”. He indicated that he did not observe his colleague’s lessons but, “what we do is that we just let the students evaluate us at the end and then we look at the pass rates”.

Dr C indicated in the interview that that students’ high school background knowledge was inadequate and that it resulted in them having difficulty with fundamental aspects of mathematics such as calculation, basis numeric skills, straight line graphs, and the parabola. In addition simple arithmetic calculations were problematic, for example:

Solve for x where $x^{1/2} = 3$.

Dr C indicated that students gave excuses such as “I don’t understand” when all they needed was practice. This, he indicated, had a lot to do with a lack of adequate background knowledge which he attributed to them no longer being encouraged to do mental arithmetic at school.

7.5 Teaching style

A summary of the general findings across lectures and tutorials is presented in the following sections.

7.5.1 General findings across lectures. The lack of collaboration between mathematics and engineering as disciplines is evident. While the 3 groups of students are streamed according to their disciplines in engineering, a situation which provides the opportunity for lecturers to draw on problems from those specific engineering disciplines to illustrate the application of mathematical concepts in engineering contexts, this is not realised. Valuable experiences in terms of relevant applications which could enhance teaching and learning were not done. The mathematics could be customized to each stream of students and made more relevant to the disciplines in which they will be used.

While the HoS acknowledges that teaching should facilitate the development of students understanding, the actual approach to teaching adopted by all three lecturers is assessment orientated and instrumental/ algorithmic, an approach which does not encourage the development of conceptual understanding. This highlights the conflict between what the Washington Accord stipulates and what ECSA as the accrediting body has committed to ensuring the degree will comply with. Furthermore, the potential to solve problems “creatively and innovatively” was difficult since students were exposed to a traditional style of lecturing. From observation of lectures, I gathered that students were encouraged to follow step-by-step procedures, rote learn formulae and rules. Their skills were limited to an instrumental understanding of mathematics which constrained the development of conceptual understanding. According to the literature algorithmic teaching leads to instrumental learning (Krathwohl, 2002; Raths, 2002).

7.5.2 General findings across tutorials. While the module outline specified that the aim of tutorials was to develop problem solving skills, what stood out is that there were no attempts to teach problem solving techniques in tutorials. This was surprising as tutorials were meant to develop problem solving skills. It seems that students were given the additional tutorial problems and were expected to develop problem solving skills by following the step-by-step procedures demonstrated in lectures and tutorials. There was little or no attempt by some tutors to identify or correct students’ misconceptions. What was demonstrated was that tutorials became a demonstration of the tutors’ ability to solve the problems. This concerned me as it was difficult to say whether students walked away with the knowledge and skills of solving the problems despite having the solutions. So while the additional tutorial questions might be well-aligned with the assessments, the data suggests that optimal use is not being made of the opportunity provided by tutorials to develop conceptual understanding and problem solving skills.

Some tutorials were managed differently by the various lecturers and were well-structured while others were not. In Dr A’s tutorial sessions, he was always present at tutorials, maintained control over the tutorial sessions, students and tutors. Tutors attended the tutorials, were punctual and prepared. They walked around the venue offering assistance to students. I can surmise that students took the tutorials seriously as their attendance was generally good, they completed the additional tutorial questions and worked independently or in groups as the need arose. They generally displayed a good attitude to their work. I inferred that this was due to the lecturer having a ‘hands on’ approach in the tutorial. Dr A’s tutorial sessions contrasted with those of Drs B and C as attendance and punctuality of tutors in their groups were a problem. This was evidenced in tutorials over the course of the semester and corroborated by Dr B who indicted his concerns with the tutors who arrived “ten minutes late or … not at all … or leave early … without even telling me ... so their attitudes are bad … and then just their ability as well … I don't know”. (Interview, Dr B, 2012). However Dr C did indicate that in spite of the tardiness tutors did a good job of tutoring. During the tutorial session some students worked in groups, some independently and others not at all. In some tutorial sessions the solutions were provided to students, an act that was generally not encouraged in tutorials since students were required to solve the problems on their own. Tutors seemed keen on providing step-by-step explanations. In some tutorials sessions, several issues concerning tutors arose. I surmised that the reason for tutors’ tardiness and approach to tutorials and the effort that students expended had to do with the lack of lecturer supervision, punctuality and attendance of tutors, small venues and student agency.

7.5.3 Rationale for teaching styles. The third research question asked: Why is teaching and learning approached in the ways that it is? I looked to the interview with lecturers and observations to provide the information that were necessary to answer the research questions. A synopsis of the salient points that arose from the data and which were considered relevant in answering the research question are presented. These include lecturers’ views about their roles as lecturers in the ME module, the nature of mathematics for engineers and their students.

Comments from Dr A and Dr B indicated that they taught in ways that they had been taught. Dr A related an incident from his experience of studying mathematics at university which was evidenced in the teaching and learning approach that he adopted. He also indicated that he used some of the examples from his own undergraduate university notes in the ME lectures. Dr B mentioned to students during lectures that the methods of solving problems that she learned at university were the same that she was demonstrating to them. There are some similarities and some differences in the way each of the three academics perceive their roles in the ME module. Dr A viewed his role in the ME module as teaching students the basics and showing them applications using real world examples. Dr B perceived his role as getting students to understand the mathematics and perhaps for students to enjoy it a little, emphasising that there was no time to show them how the mathematics is applied in the real world. Dr C saw his role as providing students with learning goals and the work that they needed to know including getting students to memorise rules and procedures and to practice typical examination problems. However the goal was predominantly to get students to pass the module. Dr A viewed mathematics as a language used in the applied sciences while Dr B and Dr C concurred on their views of the nature of mathematics stating that mathematics was a tool for solving problems of the world. The responses to how each lecturer views doing mathematics were similar. Dr A indicated that doing mathematics meant engaging in problem solving. This was in agreement with Dr B who said that doing mathematics was about attempting to solve problems and that students had to actually sit down and solve the problems. Dr C differentiated between doing undergraduate mathematics and postgraduate mathematics claiming the former was about solving problems and the latter was research-based (creating new theories, solving unsolved problems and creating new problems).

Lecturers' insight into their beliefs about students' ability to do mathematics was elicited from lecturers during their interviews. All three lecturers shared the view that high workloads and time constraints were factors that influenced students' progress. Dr A felt that all students could learn mathematics given the time but that the given time constraints were impediments to this. Dr C expressed his view that there was insufficient time to show students the relevance of mathematics in engineering contexts. He concurred with Dr A that at university "it's a fast process … it's quick so if … there's no time limit then everybody can most probably do it [but] given the time constraints they can't" (Lecturer interview, Dr C, 2012). Dr A said that due to their inadequate high school mathematics background, students were unable to understand mathematics. Dr C indicated that the mathematical ability of students was innate to an extent and if nurtured one could do undergraduate mathematics but not necessarily at postgraduate level. Dr B's belief was that there was a limit to the extent of mathematics that students could do depending on "how they were made". He felt that not all students could do mathematics as mathematics ability was inherent.

The factors that emerged from lecturers' perceptions of why students were not successful in the ME module were categorized under students' prior mathematical knowledge, their mathematical ability and work ethic. The common challenges that the three lecturers listed as obstacles to student learning were students' inadequate mathematical background (high school knowledge) which was responsible for student failure as it hindered their ability to understand the mathematics they needed to learn. Dr A and Dr B concurred that students were simply unable to learn mathematics due to their lack of mathematical competencies. Dr C indicated that the students were a diverse group (all over the place) demonstrating a wide range of mathematical competencies. Those with a good mathematical background were more independent and with hours of practice seemed to cope whereas those who lacked the necessary competencies were more dependent and required additional assistance.

Dr B suggested in addition, it was a poor work ethic on the part of students evidenced by their lack of effort. He indicated that some of the challenges he faced in the module were students' lack of diligence and rowdy behavior. He also mentioned that students needed to do the work but that they were not self-regulated learners as they did not use valuable opportunities to learn. Describing the students registered in the ME module, Dr A noted that they were dependent learners who were not confident about their mathematical ability. Dr C claimed that students were lazy and that their failure to rote learn and practice assessment type problems and absence at lectures and tutorials disadvantaged them when it came to solving problems.

The questions asking how students should go about learning mathematics resulted in diverse viewpoints. Dr A mentioned that the intention of the students was important and that while it should be to understand the mathematics, he felt that students just wanted to pass the module. Having said that, he mentioned that to pass, students needed to do the examples from the textbook and additional tutorials. Dr B agreed with these comments while Dr C said that students had to rote learn definitions and the steps for solving problems as well as practice the typical types of problems that they could expect in tests and in the final examination. All three lecturers concurred that one of the reasons for students being successful in the module was that they worked hard. Working hard meant doing the additional tutorials and mock assessments as well as attending lectures and working with the lecture notes. Dr A gave credence to downloading and using the lecture notes. He also mentioned that having a good lecturer was important. On the other hand Dr B credited successful students with sitting down and doing the additional tutorials. Dr C indicated that it was effort, rote learning and practice for most students and acknowledged that some students were gifted and perhaps did not need to put in a huge effort.

To improve the module, Dr A said that there needed to be a change in approach to teaching and testing as the approach was algorithmic and not suited to engineers who were required to apply their knowledge. Dr B was not too sure how to improve the module in terms of teaching and learning except to get students to work and perhaps to have an extra lecture for the 'weak ones'. Dr C suggested that the students lacking a good mathematical background should be put into smaller groups, their problems identified and 'fixed' as this was a stumbling block to their progress in the module. He also felt that the high workload and fast pace could be a reason for student failure.

From the data that was provided the salient points that emerged as factors that contributed to why teaching and learning is approached the way it is are the high volume of work in the short time frames, and beliefs about learners (students' inadequate mathematics background, lack of effort, dependent learners). The implications of these for teaching and learning will be discussed in Chapter Eight.

7.6 Assessment

The exit level outcomes of the module are tabulated in Table 7.2 below. Problem solving (outcome 1), application of basic and scientific knowledge (outcome2), engineering methods, skills and tools: selecting, applying, assessing (outcome 5), professional and technical communication (outcome 6) and independent learning (outcome 9) are the ECSA outcomes that were intended to be addressed in the ME module under investigation. According to the Module Assessment Matrix, these outcomes were expected to be addressed at the lowest level (level 1), indicating that they are to be slightly addressed. The official module template for the ME module stipulated three outcomes that addressed five out of the ten ECSA exit level outcomes and the level at which they were to be achieved upon completion of the module (Table 7.2).

Table 7.2

Exit Level Outcomes for the ME Module

	Aims	Outcomes				
		ELO 1	ELO 2	ELO 5	ELO 6	ELO 9
1.	Able to explain the concepts of function, limit, continuity and differentiability and solve theoretical and practical problems arising from them	√	√	√	√	√
2.	Able to calculate derivatives and anti-derivatives of elementary functions, solve appropriate problems involving trigonometric and transcendental functions and their inverses	√	√	√	√	√
3.	Able to explain the concept of integral and solve theoretical and practical problems arising from it and evaluate elementary integrals.	√	√	√	√	√

The Washington Accord specifies that the learning outcomes identified must be achieved and that measures be put in place to assess the achievement of the outcomes. The institution must show evidence that it has complied with the Washington Accord's expectation to develop and assess the achievement of learning outcomes. In the ME module while the learning outcomes are present in the ME module template the Academic Leader indicated that there was no pressure on the ME module to show that students had achieved the ELOs as they were to be addressed slightly and that there would be other opportunities within the many engineering modules for students to achieve those outcomes within the engineering degree programme.

7.6.1 Formal institutional requirements. The SAHEI CoAES handbook (2012) indicates a 20% weighting from tests and or assignments. The only form of assessment provided were tests and the final module examination which were summative assessments. ELO2 states that there will be application of scientific and engineering knowledge. The tutorial exercises from the recommended text book comprised non-contextualised problems that required application of mathematical knowledge only. An appraisal of the problems that were included in the additional tutorials revealed an absence of problems showing applications in engineering contexts. This means that only part of ELO1 could potentially be achieved since students were not provided with problems where they had to demonstrate problem solving skills in engineering contexts. Furthermore, the potential to solve problems "creatively and innovatively" was difficult since students were exposed to a traditional style of lecturing and encouraged to follow step-by-step procedures, rote-learn formulae, definitions and rules. Teaching approaches seemed to encourage an instrumental understanding of mathematics. Observations revealed that opportunities were not provided for students to achieve ELOs 6 and 9 which specify that students will be able to show competence in engineering methods, skills and tools as well as professional and technical communication. From observation of lessons, I deduced that students were rarely given the opportunity to demonstrate ELOs 6 and 9. At best, students asked questions during lectures and tutorials. Again from my observation this did not constitute evidence of professional and technical communication. The summative tests show that opportunity to develop or demonstrate competence in professional and technical communication was not provided. To develop ELO5, students would be required to show competence in using appropriate engineering methods, skills and tools, including those based on information technology. Opportunity to develop this ELO was not evidenced during lecture observations, tutorials or in assessments. This contradicts the module outcomes reflected in the CoAES 2012 Handbook which states that the students will have to demonstrate competence in the outcomes stipulated by ECSA (ECSA, 2004).

7.6.2 Blooms Taxonomy: quality of assessments. The findings of the analysis of the questions in the final examination paper are summarized in Table 7.3.

Table 7.3

The Placement in the Taxonomy Table of the SAHEI Assessments

The Knowledge dimension	1.Remember	2.Understand	3. Apply	4. Analyse	5. Evaluate	6. Create
Factual	5.1,					
Conceptual		2.3(i), 4.2, 7.1, 7.2, 8.1,	4.3, 4.4, 7.3, 8.2, 91,			
Procedural			1a(I), 1b(E), 1C(E),2.1(E), 2.2(E), 3, 5.2, 5.3, 6.1, 6.2, 9.2, 9.3, 10			
Metacognitive Knowledge						

Having analysed the final examination paper using the revised taxonomy, I compared the mock examination and final examination papers. A comparison of the mock examination and final examination papers for the ME module revealed a close match between the questions. The actual wording of the questions on both papers was the same with the exception of Question 7b. In the Mock examination paper the question read:

> Discuss (i) increasing/ decreasing and (ii) concavity and inflection points of the following function. (Mock examination paper, 2012)

Question 7. 2 in the final examination read:

> Discuss concavity/ inflection points of the following functions.
> (Final examination paper, 2012)

There were slight differences in the actual values that were used, but even those were quite close. For example, Question One in the Mock Examination was identical to the first question in the final examination paper. This is illustrated using excerpts from both papers:

Question One: Mock Examination Paper

(a) Prove that the sum of two rational numbers is rational i.e. a/b + c/d = is rational where a, b, c and d are integers and b, d are non-zero. [2]

(Mock examination paper, 2012)

Question One: Final Examination Paper

1.1.Prove that the sum of two rational numbers is rational i.e. a/b + c/d = is rational where a, b, c and d are integers and b, d are non-zero. [2]

(Final examination paper, 2012)

Similarly the a comparison of the final examination and the mock examination questions showed congruence between all the questions with slight differences in values. More comparisons have been included in Appendix G.

A comparison of the two papers question for question revealed that they were identically worded with differences in values. Results arising from the analysis of the final examination paper combined with the findings of the comparison of the two papers showed that the similarities in both papers. This brings into question whether what was considered to be on the level of *Apply* (implementation) was actually that. Since the comparison showed that the same types of problems were encountered by students prior to the final examination, the questions which were regarded as being on the level of *Application* in new situations (implementation) were not new situations at all. Dr A confirmed this in his statement:

> That is what I do not like about this course because if you look at the past year papers over the past three years, question number one is the same question, … the only thing that changes is the number”. (Lecturer interview, Dr A, 2012)

This is a matter of concern as students were privvy to the mock examination papers prior to the examination and were given sufficient time to work them out. In fact if time permitted, lecturers discussed the mock examination papers at lectures. This raises a huge concern as the papers were similar which means that students who had rote-learned or even those enaged in meaningful learning would have enhanced their opportunity to pass the paper. I can infer from this that either many students did not go through the mock examination paper or that they did not attend lectures and so were not familiar with the work, or that no learning happened in the lectures that they did attend because many students failed.

7.7 Alignment Between Lectures, Tutorials and Assessments

The assessments, including tests that were used in the calculation of the class mark as well as the final module examination, were in the format of formal tests with no feedback to students. Table 7.4 captures examples of questions included in the additional tutorials, mock tests and mock examinations, tests and examinations for the first mathematics module in the first semester. A comparison of the same shows a strong correlation among the questions presented in the additional tutorials, mock tests and examinations, the actual tests and the final examination. In effect, the additional tutorials, mock tests and mock examinations were a good indicator of the types of problems that appeared in the actual tests and the final examination. The teaching, learning and assessment policy at the SAHEI uses as one of its guiding principles the use of assessments that are an “integral part of the teaching/ learning cycle and enhances engagement with the learning task and self–assessment” (SAHEI, 2008).

Table 7.4

Comparison of Revision Exercise, Mock Assessment and Assessment

	Test revision	Mock test	Test 1
1 (a) (b)	Express the following numbers as rational numbers : (i) 2.09 (ii)32.451 (iii)100.23 Given the functions f(x) and g(x) find the understood compositions of f and g: f(x) = 1/(x + 2). (a) (fog)(x) (b) (b) (gof)(x)	Express 34,1122311223… as a rational number. (b) Let f(x) = 1/(x + 2) and g(x) = √1 – x. Find the domain of gof(x).	(a) express 25, 124124…. As a rational number. (b) Let f(x) = 1/(2x – 4) and g(x) = √3 + x. Find the domain of gof(x).
2 (a) (b)	$\|x^2 – 1\| \geq 3$ $\|2 - 3x\| > 5$	$\|x^2 – 4\| \geq 6$ $\|-3x + 2\| \leq 4$	$\|x^2 + 3\| \geq 7$ $\|-3x + 2\| \leq x; x \geq 0$
3 (a)	Simplify y long division: $y = \frac{-x^5 + 4x^4 + 2x + 1}{x^4 – 1}$	Simplify by doing long division: $\frac{-x^4 + 3}{x^2 – 3x + 1}$	Simplify by doing division or force compensate: $\frac{-2x^5 + 3x – 1}{x^3 – 2x + 1}$
3 (b)	If f is an even function and g is an odd function discuss oddness/ evenness of the following functions: (a) $f^2 – g^3$; (b) f^2g 1. Solve for x (in radians): (a) Sin 3x = -1 (b) Tan 2x = -1/√3; x € [-π, π]	If f and g are odd functions, prove that (i) f.g(x) is even and (ii) fog(x) is odd. Solve for x in radians: Sin 3x = -1/√2; x € [-π/2,π/2]	If f and g are odd functions, prove that $f^4 – g^2$ is even. Solve for x (in radians): cos 4x = -1/2 ; x € [-π/2,π/2]

(Source: Learning@sahei.ac.za, 2012)

Two examples for test one are shown here. The others are included in Appendix F.

A comparison of the questions from the additional tutorial, the revision test, the mock test and the actual test itself showed that they were all very similar and the nature and type of questions in the lecture were similar to those of the additional tutorial, the revision test, the mock test and the actual test with slight differences in the values that were used in each question. This suggests that there is close alignment between additional tutorials, mock tests, revision problems and the assessment. Drs A, B and C were in agreement that there was good alignment between lectures, tutorials, assessments and the final examination. Dr A said that despite the close alignment between the components of the module he could not justify why many students did not perform well:

> Couldn't have been more well-aligned. Trust me. Which actually implies that everything should be easy then, you doing your tuts, you doing your class work, the exam should follow through nicely: It doesn't seem to be the case. I don't know what's the problem? (Lecturer interview, Dr A, 2012)

Dr C’s response to how assessments were drawn up also pointed to the alignment between the various components (lectures, tutorials, assessments and examination) of the module:

> Well look it's clear, you’ve got a section that we have to teach … So you then give them examples of … problems and there's the textbook problems and the normal ... tut problems. So when you set the test you will base your test questions on similar … problems … I think there has to be … a strong connection between what you do in lectures, tut problems and test problems. (Interview, Dr C, 2012)

A close inspection of the problems included in the additional tutorial, test revision and mock test leading up to test one revealed a close alignment in terms of the types of questions asked. Given the similarities between the questions across all three sets of tasks, the tests were of a type that constituted ‘well-structured’ or routine questions as they are very similar to the assessment. A similar comparison of the additional tutorials, revision problems, mock tests and examinations for tests two and three were conducted. The findings were similar for the second and third tests and were evident in the following statements: “Do mock test 3. Practice similar problems in add tuts and from lectures and text book” and “test 3 will include problems based on additional tuts 9, 10 and 11” (Lecture observation, Dr A, 2012).

Interviews with the lecturers, successful students and tutors supported Dr C’s statement that there was strong alignment between lectures, additional tutorials and the assessments. According to Dr A, it “couldn't have been more, well aligned”. Similarly, all six tutors were unanimous in their view that the lectures, tutorials and assessments were well-aligned and that if students followed the structure of the module (meaning attending the lectures, doing the tutorials, additional tutorials and mock tests), they would pass the module.

Tutors' responses to the question: "Do you think there was alignment between lectures, tutorials and assessments"?, were unanimous. The following excerpt supports this:

> Yes I have noticed. Also I invigilate for tests and I notice that … what we do in lectures does give you like the basic concept. It explains the concepts and he gives you an example for it. Like in the test I'll notice whatever is in the additional tut it's the similar types of questions [that] come out in the test except that different values or there's some maybe a small trick to it. But it's the exact same stuff as the additional tut so if they did do all their additional tut they will be able to at least pass or get a really good mark, an A or something in their test if they work hard on their knowing their concepts and did their tutorials, did their additional tut. (Interview, Tutor C, 2012)

Successful students who were interviewed were of the opinion that there was definitely a positive alignment between the three components of the module. Of the fourteen students interviewed, thirteen of them indicated that there was strong alignment between lectures, tutorials and assessments (Appendix H).

The perception of successful students echoed this finding as confirmed by Student B:

> Tests were very beneficial in preparing us for the exam. They were very similar to the type of questions in the exam … [and]… additional tutorial is more beneficial than textbook questions. I think the mock exam is very good in showing us what the final exam would be like ... the standard, the types of questions, the way the questions are phrased and such. (Interview, Student B, 2012)

Data from the student questionnaires provided some insight into whether students felt the lectures, tutorials and assessments were aligned. In response to the question on the questionnaire: Was there good alignment between lectures, tutorials and assessments?, a frequency count revealed that close to 83% of the students felt that there was good alignment between the three components of the module. While the question aimed to determine whether lectures, tutorials and assessments supported each other and led to the achievement of the module outcomes, some students interpreted the question to mean: Does the content and timing of the content covered during lectures match what is needed for tutorials and assessments? This became evident during data capture when I encountered responses like the following: “at times syllabus was ahead of tests and work done in tutorials did not follow work done in lectures and tut on Monday but work only covered later in the week and the test dates were too close to each other, insufficient time to study well” from those who responded negatively to this question. Students who responded positively indicated similar interpretations of the question as indicated: “Sections were dealt with accordingly and around the same time frame and what we did in lectures that week, were in the tuts and at lectures we start a new chapter that will be on tutorial questions that same week”. Those students who interpreted the question as I had intended responded in the following ways: “Assessments are very similar to content from lectures and tutorials and they all linked to each other and tests and the tutorials were always linked with the sections taught in the lectures which also correspond with the tests” and “all supported one another and there was a good balance of these 3 aspects and they were all driving for the same goal”. A student noted that “lectures were about understanding. Tutorials about clarity and assessment about delivering what you understand”.

Another perspective of ‘alignment’ that emerged is that of lectures, tutorials and assessments being close in terms of preparation as indicated by a few students: “mostly what appeared on assessment was what we learned in class and did in tutorials and the way we were taught, was exactly how the questions were asked and much of the tutorial style of questions were done in lectures and appeared in tests and assessments were almost identical to tutorials”. The impression I received was that students were ‘coached’ in all three components and that those who recognised the ‘code’ and followed the coaching carefully benefitted. While the objective of this question was to ascertain whether lectures, tutorials and assessments were constructively aligned to achieve the learning outcomes, the responses provided some insight into the sequence and pacing of the content which evidently proved to be a challenge for some students. This is an important finding and deserves further investigation. However that investigation is not within the scope of this study.

The justification provided by some of the students who indicated that there was no alignment between the modules follows: “sometimes examples done in class were too easy compared to questions asked in tuts and lectures were not well planned and did not prepare us for tests” (Questionnaire, Student 215, 2012) and “tutorials were always more difficult than lectures or assessments” (Questionnaire, Student 12, 2012). It was established in Chapter Two that the distributive, recontextualising and evaluative rules interrelate to relay society’s power relations and pedagogic practices which mediate access to knowledge which ultimately serves to include or exclude students. Consequently different social groups gain access to different forms of knowledge and therefore differentiated access to the possibility of new knowledge, and thus the 'thinkable' or official knowledge" (Bernstein, 1996, p. 117). Based on this I can surmise that for these students, access to new knowledge was not provided and this resulted in students not understanding how to make the best use of the teaching and learning activities.

The concern this raises is whether the extremely high level of correlation or congruence between tutorials, mock assessments and assessments is desirable and whether it will lead to the development of higher order cognitive skills, more especially the module outcomes and ELOs specified. Assessments appear to be framed on a 'teach and test what is taught' approach as confirmed by the head of school.

7.8 Conclusion

In this chapter, the teaching styles and rationale for each lecturer were presented. The questions in tutorials, mock assessments and assessments were analysed using Bloom's Revised Taxonomy to determine the cognitive demand of the questions. The questions, on their own, were found to be of a higher order of cognitive demand. However combined with the knowledge that problems of the type included in the tests and final examination were well-rehearsed in tutorials and mock assessments, they were not novel and so reduced the cognitive demand that was initially established in the analysis. A comparison of the questions across the tutorials, mock assessments, revision assessments and assessments was conducted to determine the level of congruence between the questions. The comparison revealed a high degree of congruence between questions. The next chapter is a discussion of the findings presented in Chapters Five, Six and Seven.

Chapter Eight
Discussion

The broad aim of this study was to explore how teaching and learning is approached in the first mathematics module for engineering students at a SAHEI. Given that this is a case of teaching and learning in the ME module, the overarching aim was articulated in three research questions. The first research question aspired to gain an understanding of the role of mathematics in engineering as it was anticipated that insight into the mathematical demands of engineering would underscore the need for this study. The second research question sought to explain how teaching and learning is approached in terms of the constitution and structure of the content, teaching approaches and assessments. In attempting to understand the philosophies underpinning teaching and learning in the module, the third research question sought to understand why academics approach teaching and learning in the ways that they do. Each research question is presented with a summary of the findings and the implications of these for teaching and learning. Following this, based on the findings, recommendations for the improvement of teaching and learning in the ME module are presented. This chapter is presented according to the research questions using the three message systems as a framework for the discussion

8.1 Role and Relevance of Mathematics in Engineering

The findings of the first research question were presented in Chapter Five and provided insight into the various internal and external views on the role of mathematics in engineering both within modules in the degree as well as in engineering practice. Document analysis and interviews with academic staff in mathematics and engineering were used to generate data to answer the research question. The SAHEI by virtue of it being a signatory to the Washington Accord has international endorsement of its engineering degree programmes (International Engineering Alliance, 2013; ECSA, 2012; Islam, 2012). Engineering degree progammes form the basis for developing professional engineers making it necessary for it to be accredited by ECSA, the national accrediting body, an accreditation that has been granted to the SAHEI. Engineering as a regulated profession requires professional engineers to register with ECSA.

The findings reveal that the SAHEI engineering degree programme and the modules that constitute it, including the ME module, meet the international benchmark standards in terms of the mathematics content that is considered necessary for engineering although there is no consensus on the extent to which each topic within the curriculum should be taught. At the international level, the level of the Washington Accord, and amongst signatory countries, the framing over selection of content is weak. While there are recommendations for the topics that the mathematics content should include, there is no firm requirement as to which topics must be included or to what extent each of the topics should be taught. While the Washington Accord states that the quality of the engineering degree is dependent on the design of the curriculum, teaching, learning and assessment, a specific curriculum in terms of the structure of the module and teaching and learning is not specified. Again this indicates a weak framing over the selection of content in the module.

Debate over what mathematical content is appropriate for engineers is ongoing as some argue for a balance between abstract, theoretical mathematics and its application claiming that while technological advances has made mathematical computation easy, the interpretation of the results require a deep mathematical understanding which can be achieved by theoretical explanations while others claim that studying the theory of mathematics is not necessary (Bickley, 1964; Sazhin, 1998). Proofs of theorems were not specifically included in the ME module content. The HoS indicated that lecturers had the flexibility to include proofs at their discretion thereby indicating that to some extent the framing over the inclusion of proofs was weak. Theoretical explanations of mathematical concepts were also not included at the level of the classroom (lectures). This seems to suggest that the role of mathematics was limited to that of rules, principles, procedures and application, giving credence to it having an instrumental role in engineering. In essence it seems that the role of the ME module is seen to be that of a toolbox. Consequently it can be debated whether the content in its current form encourages the development of conceptual understanding and whether it provides access to powerful knowledge (Young, 2009) and abstract theoretical knowledge (Bernstein, 2000) (discussed later).

Differing views of the role of mathematics emerged from the data, with ECSA, the HoS and the Deputy Dean expressing the view that mathematics must develop a way of thinking and that engineering students require the ‘full range of mathematical abilities’ suggesting that the content in the ME module should provide opportunity for students to develop conceptual understanding. The CoAES handbook (2012) indicates that the purpose of the ME module is to introduce basic mathematical concepts of differential and integral calculus while the perceptions of the lecturers in the module highlighted the role of mathematics as a toolkit comprising rules, formulae, definitions and procedures, strengthening the view that the ME module provides a mathematical toolkit for engineers. The absence of proof and theoretical explanations, the focus on rules, principles, procedures and application further entrenches the notion that mathematics is seen as a tool for engineers. The different views of the stakeholders may have implications for how teaching and learning is approached in the ME module. These will be discussed in more detail later in this chapter. The next section presents a brief summary of the findings from the second research question and their implications.

8.2 Teaching in the ME Module

The second research question asked: How is teaching and learning in the ME module approached in lectures, tutorials and assessments? To respond to this question, observations, interviews and document analaysis were used to elicit data and analysed qualitatively. This section thus presents a concise summary of the analysis of the pedagogic device, lecturer teaching styles and the conceptual demand of questions in tutorials and assessments. Bernstein’s concept of the pedagogic device was used to examine the recontextualisation of knowledge in the construction of the ME module while the concepts of singulars and regions were used to examine the tensions in the ME module which as a result of its’ position both as a service module provided by the department of mathematics yet offered in the engineering curriculum, is potentially a site of conflict and struggle. Teaching and learning in the ME module were analysed using Bernstein’s concepts of classification and framing. Teachers’ philosophical and epistemological conceptions were used as a framework to analyse lecturers’ teaching styles. The quality of the final examination was determined by using Bloom’s revised Taxonomy to evaluate the level of conceptual demand of the questions.

8.2.1 The pedagogic device. The pedagogic device comprises the distributive, recontextualisation and evaluation rules. The recontextualisation and evaluation rules were found to be pertinent to this study and were thus used in the analysis of teaching and learning in the ME module. The recontextualisation of the ME module was examined and the findings presented in Chapter Six. In this section, the recontextualisation of the ME module and implications of it which occurred at the level of the ORF, PRF and the lecture room are discussed.

Recontextualisation occurs at the macro and micro level in the ME module.

Recontextualisation refers to the transformation of knowledge from the academic discipline (field of production) through to pedagogical knowledge (field of reproduction). To analyse the transformation of content from the academic discipline of mathematics to the ME module, international, national and local influences which acted to shape the content of the ME module were examined. On the macro level the influence from the Washington Accord was realized in that the topics included in the ME module were compliant and consistent with those loosely included in the Accord as well as with those in the signatory countries. ECSA, within the ambit of the ORF, suggests that the engineering degree programme provide a thorough grounding of mathematics that will enable further study in traditional or related emerging fields. I inferred from this that the theoretical underpinning of mathematical concepts should be included although it was not evidenced in lecturers' instructional practice. At the level of the PRF, the textbook was found to be an influence on the current curriculum as the selection and sequence of topics and tutorial exercises in the curriculum document were strongly aligned to that of the textbook (proofs were not specified) and were followed in lectures. Furthermore while the section on Elements of Logic was included as one of the topics covered in the module it was omitted at the micro level which is the level of recontextualisation in the classroom. This shows that lecturers did have some degree of control (weak framing over selection) over which aspects of the content were excluded. From my interviews, the exclusion of the section on Elements of Logic did not seem to be regarded as an issue for either the mathematicians or the engineers as this was not called into question. Recontextualisation from the academic discipline to the ME was also evident in the exclusion of theoretical explanations (and proofs) of mathematical concepts. Recontextualisation at the macro and micro levels could have been influenced by the textbook (PRF), the perception of lecturers that students were under-prepared for mathematics in higher education and the tight time constraints given the high volume of work that had to be completed in thirteen weeks of lectures.

The regionalization of the ME module makes it a site of conflict and struggle. The ME module is a product of the regionalization of mathematical knowledge. While mathematics per se constitutes a singular in the academic discipline of mathematics (singular), that is it looks inward toward the discipline, the ME module in the engineering curriculum constitutes a region as it faces both inward toward mathematics and outward toward engineering. The findings which resulted from analysis of the curriculum document, the CoAES handbook 2012, ECSA documents, and an interview with the HoS, reflect that the pedagogic device in the ME module as a region, is a site for "appropriation, conflict and control" (Bernstein, 2000, p. 28). This is due to its precarious location in the engineering curriculum while under the control of the department of mathematics. There is a struggle between the department of mathematics and the school of engineering for ownership of the pedagogic device as "those who own the device own the means of perpetuating their power" (1996, p. 117). The mathematics department, being the 'owners' of the device, attempt "to establish their own ideological representations" (Bernstein, 1996, p. 117) by controlling the *what* and *how* of pedagogic practice thus entrenching their views of what mathematics is relevant for engineers and how it is to be known in the ME curriculum. Furthermore, the tension in the current recontextualisation of the module and conflict over engineering's voice in its construction, is evident in the HoS's response that engineering has been 'allowed' to make changes in the past but that would no longer happen in the future. This contradicts the HoS's calls for closer interaction between mathematics and engineering and calls into question the need for closer interaction if engineering is to be denied a voice.

Engineering as a region is also subject to the influence of the professional body (ECSA) which influences the construction of the ME curriculum. This influence is realized in the identification of specific exit level outcomes that the ME module must aspire to achieve or show progress towards. The evidence shows that in theory the ME module lists the ECSA ELOs as outcomes, but in practice, evidence to suggest that opportunity was created for students to develop these outcomes was lacking. This implies a conflict between mathematics and engineering with regard to the ELOs as although mathematics has power and control over the ME module it does not satisfy the requirements in terms of providing opportunity for the achievement of the ELOs that ECSA requires engineering students to achieve.

The exclusion of proofs, derivations and theoretical explanations from the ME module constrains access to abstract theoretical knowledge and powerful knowledge. The philosophical approach of the head of school, lecturers in the ME module and in engineering seem to differ fundamentally. The head of school is convinced that mathematics should develop “a way of thinking for the engineer” that requires the study of pure mathematics, which includes proofs and Elements of Logic. Lecturers in engineering confirmed that mathematics is a key component of engineering modules and that, certain engineering modules “require the full range of mathematical abilities”. I can surmise from these responses and the literature that conceptual understanding and the ability to apply the mathematics are important aspects in a mathematics course for engineers (Bickley, 1964; Sazhin, 1998). Mathematics lecturers on the other hand perceive mathematics for engineering students as a tool that can be applied to solve problems and teach accordingly. The question this raises is whether the ME module provides students with the mathematical proficiency that they require to participate effectively in subsequent engineering modules, in engineering practice and in producing new knowledge. The evidence collated thus far seems to point to the need for engineering students to have a good theoretical grounding in mathematics.

In Chapter One I outlined the institutional goal and reasons for underscoring research and postgraduate study at the SAHEI. The recontextualisation of knowledge at the macro and micro levels resulted in the omission of proofs and Elements of Logic in the ME module suggesting that the intention of the mathematics department is to enable engineers to apply the mathematics but not necessarily to understand the mathematics or use it to become knowledge producers. This runs contrary to the head of school’s statement that the school of engineering should stop perceiving itself “as producing engineers” and that engineers have not “fully bought into the idea of research-led discourse at the university” (Interview, HoS, 2011). I can infer from this that the SAHEI, being a research-led institution, should underscore research in engineering and that a good grounding in mathematics would serve to enhance research in this discipline. The intimation is that engineering as a discipline should reconceptualise its role as not only ‘producers’ of engineers but also as producers of knowledge, researchers and research in engineering. The various perspectives presented in Chapter Three (Bernstein, 2000; Bickley, 1964; Sazhin, 1964; Young, 2009, 2010) support the view that the potential for research and postgraduate study is possible given that students have access to theoretical knowledge. This means that engineering students should have access to what makes mathematics, and what provides access to the potential for new possibilities in engineering suggesting that the omission of theoretical knowledge from the ME curriculum does not necessarily promote access to further study and research. This is in conflict with the institutional goal.

As mentioned in Chapter Three, those with access to higher education have access to knowledge of the powerful (Young, 2008). This knowledge defines what counts as legitimate knowledge and who has access to it (Bernstein, 2000). In this section I argue that while students in higher education have access to knowledge of the powerful, the ME module does not necessarily provide access to powerful knowledge and serves to exclude those who are already on the periphery looking in. Powerful knowledge provides access to new ways of thinking about the world and provides students with a language for engaging in "political, moral and other kinds of debates" (Young, 2008, p. 14). According to Young access to powerful knowledge is access to specialized knowledge and is best facilitated by discipline experts in higher education. He indicates that graduates require theoretical knowledge to function effectively in an increasingly complex society. Young claims that the difference between specialist and pedagogic knowledge is that the former is context independent while the latter is context dependent. Context independent knowledge forms the basis for making universal generalizations and thus constitutes powerful knowledge. Young states that "what makes powerful knowledge powerful is its independence or autonomy from the specific contexts of its origin" (Young, 2009, p. 13). The concept of powerful knowledge provides epistemic access to the discipline. At the SAHEI the ME curriculum includes the introduction of basic mathematical concepts and their applications but not proofs, theorems or theoretical explanations, thereby depriving students of access to the theoretical understanding of the mathematics taught.

This calls into question whether the 'way of thinking' purported to be necessary for the 21st century engineer has the potential to be developed given the lack of theoretical knowledge and logic in the ME curriculum. Bickley (1964) contends that abstraction is the life and soul of mathematics. Mason (2001) supports the inclusion of theoretical knowledge when he says that mathematics learning is a process of developing facility and understanding concurrently, by constructing the knowledge that others have proven. Sazhin (1998) argues the merits of studying mathematics in abstraction and claims that some theoretical knowledge is necessary but that studying it *ad infinitum* is not. The ME module provides access to the formulae, rules and procedures giving students access to procedural knowledge without the theoretical underpinning making it dependent on the ‘specific contexts of its origin’. This is supported by the statement made by an engineering lecturer: “what are you teaching these students, they don't know how to apply” (Lecturer interview, Dr A, 2012). In the light of the institutional vision and what the head of school has said with respect to research in engineering, the question that is raised is whether students have access to the mathematical knowledge that will enable them to develop the way of thinking which engineers require. The literature suggests that without theoretical knowledge engineering students do not develop the ways of thinking that engineers require. Bickley’s (1964) assertion that engineers should have access to abstract mathematics supports the argument that engineers should be better mathematicians.

The lack of theoretical underpinning in the ME module is more concerning when one considers the role of mathematics in perpetuating the development of new knowledge in mathematics. Bernstein contends that access to theoretical knowledge provides access to the ‘unthinkable’ and the ‘not-yet-thought’ and to ‘new ways of thinking about the world’ (Bernstein, 2000; Young, 2009). Mathematics and engineering have a reciprocal relationship as development in engineering spurs development in mathematics (Bickley, 1964) as well as in promoting research within engineering disciplines in a research-led institution. Without the theoretical understanding of mathematics, the reciprocal relationship between engineering and mathematics (Bickley, 1964) is constrained. Bickley (1964) suggests that mathematicians should be better engineers and that engineers should be better mathematicians so that enhancement in both can be promoted. Bordogna *et al*. (1993) claim that engineers are “responsible for applying new knowledge to create what has never been” (p. 4) which calls for the intellectual development of engineering students to make connections between disciplines that produce deeper insights. The above statements view engineering as not just a discipline whose value is seen in the field of practice but one that contributes to the field of knowledge production thus supporting the Head of School’s contention that engineers should envision themselves as knowledge producers. Depriving students of theoretical knowledge, constrains the potential for students to develop the intellectual capacity required to engage in creating new knowledge thus contributing to the knowledge base. This has implications for research in engineering within the SAHEI. It also has ramifications for how effectively graduates of the SAHEI can participate in applying new knowledge to create what does not yet exist, that is providing access to the unthinkable.

Young (2005) speaking in the context of vocational qualifications, argues that education should prepare students for employment as well as for further study in their field. He suggests the implications for teaching and learning are to underscore theoretical knowledge in the way that it is provided to students. The links between the field of production of knowledge (mathematics as a singular) and that of engineering (region) must find the balance between a focus on the professional sector as well as on the intellectual development of the student (Bernstein, 2000). This again highlights the need for balance between theoretical knowledge and application of mathematical skills, encouraging a narrow understanding of mathematical concepts. In the ME module, the balance between theory and application is skewed in favour of application. The value of theoretical knowledge is made clear in Young's argument that content provides access to concepts which form the basis for student learning since academically speaking, student learning is a matter of conceptual development. He says that whereas the content might not be remembered in the long term, concepts will still be drawn on. As such content acts as a carrier for concepts since conceptual development is mediated through content (Young, 2010).

The pure mathematics module is viewed as a singular in that it is narcissistic, focusing only at its own development. The ME module falls within engineering which is a region, meaning that it faces both inward towards the academic discipline and outward towards the field of practice. However the ME module has been specialised for engineering and the recontextualisation of mathematics from the field of production to the field of reproduction in engineering has excluded mathematical proofs, thereby diluting the module and calling into question both its knowledge form and whether it is truly academic in nature. It was shown in Chapter Five that the ME module will not be credited against the pure mathematics module because they are not academically equivalent.

Mathematics is considered by some to be "the ultimate form of logical rigour" (Blockley and Woodman, 2002, p. 1) and that solving problems using logical rigour is an important quality for engineers to acquire. The value of logic and rigour is argued by Blockley and Woodman (2002) who understand that rigour in mathematics is absolutely pertinent to engineering and that consequently engineers need to acquire that quality. They note that being able to solve problems using logical procedures is important as the use of these procedures facilitates the engineers' understanding of how to use mathematics comfortably, effectively and appropriately (Blockley & Woodman, 2002). That the mathematical topic, Elements of Logic, has been intentionally excluded from the curriculum in effect means that engineering students will not have access to the rigour that Blockley and Woodman claim is a necessary attribute for engineers. This highlights the need for those involved in the construction of the ME curriculum to understand the role and relevance of mathematics in the engineering curriculum. This can be enhanced through discussion and debate between academics in the disciplines of mathematics and engineering. However an ongoing, collaborative relationship between lecturers of mathematics and engineering, both of whom are an integral part of engineering education at the SAHEI, is conspicuously absent.

The literature supports collaboration between the mathematics and engineering departments as it clearly shows that advances in technology create situations that require mathematical solutions which can speak to the changing engineering needs which in turn fuel research and advancements in mathematics. The reciprocal relationship between mathematics and engineering has been shown to be important in developments in both. The constantly changing landscape of engineering as well as in higher education requires a constant review of the role of mathematics in engineering and that of engineering in mathematics. For example mathematicians at the SAHEI are currently using their expertise in Graph Theory (Mathematics) which they apply in Health and Biological Sciences and which has facilitated research to better understand HIV, its link to diseases and to find ways to prevent the spread of HIV. This has spurred the development of novel areas of application for mathematics in new and diverse fields and opened up research in mathematics as well as other disciplinary areas.

The pedagogic device is evidently a site for conflict and struggle as pointed out by Bernstein (2000). The HoS claims that engineering has had too much influence on the mathematics modules for future engineers in the past and that with the new structure that influence will be somewhat reduced. On the other hand the HoS's acknowledgement that there needs to be greater collaboration between mathematics and engineering academic staff, calls into question the need for collaboration since the interview clearly revealed that the School of MATHEMATICS 'owns' the mathematics modules for engineering students and that the engineering voice will be minimized. The literature review as well as the findings of this study underscores the interdependence between the disciplines of mathematics and engineering, foregrounding the need for collaboration between academics in both the disciplines. However, the Head of School's stance indicates the potential for greater alienation between two disciplines, especially since he indicated in the interview that the plan for the future was for mathematics to be "*teaching the same content … to both students* [engineering and science]". The HoS's intention to offer only the pure mathematics module will mean the exclusion of some specialised topics offered specifically to engineering students in the ME module (Winter & van Heerden, 2012) but will include proofs, theoretical explanations and derivations. The lack of collaboration between the two disciplines is noticeable since engineering academics were not consulted on this decision, further emphasising the dialogic disconnect between the two disciplines.

While I acknowledge that the 'way of thinking' purported to be developed is highlighted in the literature as an important outcome, I also understand from the literature that it is necessary for engineers to have knowledge of and be able to apply the mathematics per se in an engineering context, requiring that mathematics topics currently included in the mathematics module for engineers be maintained. The conflict between the two disciplines is further emphasised by the constant attempt by engineering "to cut down the content" to reduce the amount of mathematics that engineering students take, yet the HoS indicates that "won't happen". This highlights the lack of dialogic communication between engineering and mathematics regarding the role and relevance of mathematics to engineering and emphasises the divide between the two disciplines. This conflict in itself validates the need for a dialogic relationship between mathematics and engineering.

In addition integral aspects of mathematics such as proofs and Elements of Logic, were excluded thereby diluting the mathematics and compromising the integrity of the mathematics offered to engineering students by excluding key sections of mathematics that provide access to theoretical knowledge and what Young (2009, 2010) describes as powerful knowledge. The implications of this were discussed in the preceding section.

Structure of the module. Bernstein (2000) contends that education is the specialization of consciousness with respect to that of the institution and aims to develop context independent meanings. The specialization of consciousness occurs through the concepts of classification and framing. Classification refers to the relations (degree of insulation) between categories where categories could refer to agents, discourses or spaces. Classification is strong (C+) when there is strong insulation between categories or weak (C-) where the insulation between categories is weak (Bernstein, 2000). The structural aspects of the module were analysed using Bernstein's concepts of classification and framing. Evidence collected from the curriculum document, observations, interviews and the student questionnaire revealed that the module is highly organised with respect to content. Analysis of the content evident in the formal curriculum document and in lectures revealed strong classification of content on an interdisciplinary, intradisciplinary and interdiscursive level. This suggests that the content was distinctly mathematical and clearly outlined the *what* of the ME module. The strong classification of content, according to Bernstein (2000), facilitates the development of recognition rules (Bernstein, 2000) which is a necessary step towards acquiring the realization rules leading to the production of the legitimate text. Be that as it may, the strong classification of the content during the transmission process also meant that applications in relevant engineering contexts were not demonstrated. In addition in lectures, the classification over spaces was strong as was the classification of hierarchical rules. While some authors contend that strong classification advantages working class students (Bernstein, 2000; Case, 2011; Maton, 2009; Muller; 1998; Bennet, 2002) others favour more progressive methodologies that promote weak boundaries between categories (interdiscursive, intradisciplinary and interdisciplinary) (Bordogna, Fromm & Ernst, 1993; Felder, Woods, Stice & Rugarcia (2000) ; Herrington, Reeves, Oliver & Woo, 2004; Klingbeil, Mercer, Rattan, Raymer & Reynolds, 2005). This section discussed classification in the ME module. The next section discusses framing over selection, sequencing, pacing and evaluative criteria.

Framing refers to the relations within categories and can be strongly (F+) or weakly (F-) framed. Weak framing indicates that students have more apparent control over selection, sequencing, pacing and evaluative criteria while strong framing indicates students have little or no control over the selection, sequencing, pacing and evaluative criteria. In lectures, the framing over selection, sequencing, pacing and evaluative criteria was found to be strong. This was not the same for tutorials as while there was strong framing over selection, sequencing and pacing for each week's tutorial, framing within the tutorial sessions varied according to the lecturer. In Dr A's tutorials, there was strong framing over selection but weak framing over sequencing and pacing. This meant that students had to complete the tutorial questions but had a choice of the order and length of time they wanted to spend on each question. They could leave the tutorial when they completed their work. The tutorial sessions supervised by Dr B and Dr C, showed very weak framing over selection, sequencing and pacing within the tutorials session. This meant that students were not compelled to complete the problems within the tutorial. The strength of the evaluative criteria can be debated. On the one hand, the evaluative criteria in terms of explicating the legitimate text that the student was required to produce were explicit in all three lecture groups as students were clearly told what was expected, shown step-by-step procedures on solving routine problems, told how to learn the content and given sufficient assessment type examples to practice. In addition, tutorials provided the opportunity for students to identify what was missing from their solutions as they could discuss their solutions with tutors and request assistance when necessary. On the other hand, there were no formative assessments and feedback on assessments was not provided, thereby depriving students of the opportunity to determine what was missing from their texts.

To determine whether the tutorials, mock assessments and assessments, emphasized the evaluative criteria and to establish the alignment between the three, a comparison between additional tutorial questions, mock assessments, tests and the final examination showed congruence between the types of questions asked. This comparison evidenced explicit evaluative criteria since students were provided with clear examples of the legitimate text that they were required to produce. In addition, the lecturer provided on-line solutions for the additional tutorials and assessments which all students had access to. Although students did not get individual feedback on their work, they could use the solutions provided to ‘figure out’ their mistakes. The danger is that students could use the solutions to learn off answers rather than to identify their own errors. From the evidence it was thus difficult to assess the strength of framing over the evaluative criteria.

The strong classification and framing in the ME module has implications for teaching and learning and these are discussed in the following section.

The strong classification of the module facilitates access to theoretical understanding and access to powerful knowledge? Young (2010) refers to boundaries as boundaries of access and boundaries of constraint since boundaries are as much a condition for providing access to powerful knowledge as they are in constraining access to the same. The strength of boundaries will determine who gets access to what (Bernstein, 2000). Analysis of the ME module revealed that it is strongly classified. Strong classification results in little or no application in relevant engineering contexts and privileges the lecturer as the source and transmitter of knowledge. According to Bernstein, strong classification is considered appropriate in a learning context since students do not yet have the tools to select content and therefore cannot construct the ‘not yet thought’ (Bernstein, 2000). Furthermore, strong classification over content facilitates the development of recognition rules that enables students to recognize what constitutes the legitimate text or what is to be produced. Acquiring the recognition rules facilitates the development of realisation rules and thus the production of the legitimate text. With respect to the points made above, indications are that the strong classification of the ME module is beneficial to students.

In the context of this module, strong classification of content means that the mathematics offered to engineering students does not show application in relevant engineering contexts. Craig (2010) claims that teaching mathematics without showing its relevance to engineering contexts, while still valuable, disconnects mathematics from engineering. The result of this disconnect are students who lack the ability to make connections between disciplines (Bordogna *et al*., 1993) thereby limiting students’ development of conceptual understanding to the discipline. Then again, Case (2011) contends that content which is weakly classified in the curriculum is potentially damaging for students from disadvantaged backgrounds as their backgrounds constrain their ability to differentiate between the various knowledge forms. She claims that teaching and learning approaches in which the content is grounded in the context (for example PBL) are detrimental to the very students whom they are designed to help. She rationalizes her claim stating that context dependent content disadvantages students in that their knowledge remains grounded in their own contexts and serves to inhibit their ability to generalize or develop abstract understanding. Weak classification implies content that is not distinctly visible making it difficult to acquire the recognition rules that facilitate acquisition and production of the legitimate text. This is likely to be more the case for students from lower socio-economic backgrounds but is not necessarily the case for middle class and upper class students who by virtue of their home background are likely to be more familiar with the different forms of knowledge in the educational context (Bernstein, 2000). The solution does not have to be a dichotomous choice between including or excluding application in relevant engineering contexts but a balance between mathematics and its application (Sazhin, 1998; Mason, 2001, Williams *et al*., 2003, Henderson & Broadbridge, 2007).

Strong classification of content presents students with the space to develop a specialised identity with specialised internal rules and voice. Hence based on the strong classification I can infer that the specialised identity and voice that is developed in students is purely mathematical. Furthermore while the identity being developed is mathematical, the focus on rules, procedures, definitions, and the exclusion of proofs entrenches the view of mathematics as a toolbox. Although mathematics is core in engineering education and engineering practice, it is needed in a way that facilitates computation, application and the interpretation of results. The unique specialised mathematics identity of the ME module privileges the view of mathematics as a toolbox consisting of rules, formulae and definitions that students are taught to apply. This creates a situation where students know what to do without necessarily understanding why they do it or in which situations to apply them. According to Resnick (1988) the toolbox approach promotes specific rules for specific types of problems that will enable students to find 'the' correct answer potentially resulting in students who miss the opportunity to develop conceptual understanding and to engage in meaningful learning (Resnick, 1988). This combined with the lack of theoretical underpinning and proofs, limits students' potential to interpret results of mathematical computations, a skill which is deemed to be critical to engineering practice in the 21st century (Blockley & Woodman, 2002; Henderson & Broadbridge, 2007; Lopez, 2007).

The strong classification of the content in the ME module reflects the dominance of the mathematics department over the ME module and ensures that its specialised identity is maintained and reproduced through its insulation from other engineering modules, discourses and every day knowledge (Bernstein, 2000).

Strong framing of the module does not necessarily enhance teaching and learning. The framing over selection, sequencing, pacing and evaluative criteria was found to be strong in lectures. Strong framing describes who controls the pedagogic relation (Bernstein, 2000). The strong framing of the ME module indicates the strong control of the mathematics department over the social relations governing the ME module (Bernstein, 2000). Furthermore the relationship between lecturer and students is clearly hierarchical as the lecturers governs the relationship between transmitter and acquirer (Bernstein, 1996) thereby making explicit the boundaries (Mclean *et al*., 2011). Lecturers and students have little control over the pedagogic relation in terms of the content. The HoS did acknowledge that lecturers had control over the decision to include proofs. While this might be true, lecturers did not include proofs but had control over whether to exclude the topic: Elements of Logic. The literature suggests that strong framing over selection, sequencing and evaluative criteria with weak framing over pacing creates optimal conditions for student success (Bernstein, 200; Morais, 2002). It optimizes the opportunity to acquire the recognition and realisation rules which lead to the production of the legitimate text, in this case the correct solutions (Morais, 2002). However the framing over pacing in the ME module was very strong, which meant that students could not learn at their own pace thereby decreasing the opportunity for them to acquire the recognition and by extension, the realisation rules (Bernstein, 2000). This would inevitably decrease their chances of producing the legitimate text and in so doing, lead to failure amongst students. This suggests that the high failure rate amongst first year students in the ME module can be attributed to the very strong pacing of the content combined with strong classification over hierarchical rules and space.

The strong framing over evaluative criteria evident in lectures increases the chance of acquiring the recognition and realisation rules (Bernstein, 2000; Morais, 2002; Morais & Miranda, 1996), thereby enhancing the opportunity to achieve student success (Bernstein, 2000). Although students did not get individual feedback they had access to the correct test solutions from the website. This does not necessarily enhance student's learning as Rust (2002) indicates appropriate feedback should address how students did not meet the outcomes and suggestions as to how to improve if it is to enhance learning. Students are thus deprived of the opportunity to identify their strengths and weaknesses and therefore to develop their own learning (Chickering & Gamson, 1987; Rust, 2002). Assessments are perceived as drivers of change (Seymour, 2000) and since lecturers themselves do not mark the tests, teachers are deprived of the opportunity to assess the effectiveness of their strategies and to improve what they do (Seymour, 1999).

The strong classification and framing of the ME module is reflective of a hierarchical distribution of power and principles of control that privilege a dominant code and thus a hierarchical social structure. There is little indication of how the mathematics fits into engineering signifying that the mathematics curriculum can be referred to as a collection code. In the ME module the teacher is seen as an authority in disciplinary knowledge, lecturer-student relationships in lectures are hierarchical. Framing relays principles of control and in education it regulates how knowledge, skills and dispositions are transmitted and acquired (teaching and learning). From the data it seems that the locus of control in the ME module lies with the mathematics department, particularly the Head of School. In the ME module, students are encouraged to rote learn and rehearse mathematical formulae without theoretical understanding of the concepts. But lack of access to theoretical knowledge in itself limits access to complete understanding (Prosser & Trigwell, 1999). From my assessment of the literature, it seems that this combined with a learning environment that encourages surface approaches to learning, could explain why the number of students who pass the subsequent mathematics module on the first attempt is 42%.

If the evaluative criteria are explicit why do students still fail? According to Bernstein (2000), strongly framed evaluative criteria create conducive conditions for success. So the question that is raised is, despite strong framing over evaluative criteria, why are students failing? This is evident in the total first year throughput of the 2011 cohort (across both mathematics modules in the first year) which is 15% while that of the 2012 cohort is 15% as well. This is a matter of concern as responses from the student questionnaire showed that 83% of students felt there was good alignment between lectures, tutorials and assessments. This suggests that students acquired the recognition rules as they were able to identify the correlation between assessments, tutorials and lectures. I can surmise that students either did not acquire the realisation rules or that there were other reasons which can account for why students fail despite the structuring of the module in ways that according to Bernstein (2000) could optimize the chances of student success.

Feedback on assessments, marking criteria and corrections were not provided to students. Students were provided with the type and level of questions that they were expected to answer, what they were required to know for assessments and the ‘model answers which were provided to students but were not explained to them. This reduced the opportunity for students to “identify what is missing from their textual products; of clarifying concepts; of leading them to make synthesis” (Morais *et al.*, 2004, p. 8). If students’ work was corrected, they would have had the opportunity to self-evaluate, thereby increasing the opportunities to produce the legitimate text. As it stands, their potential to produce the legitimate text was thus reduced. This could be a reason why some students were not successful in the ME module.

But students’ work was also not corrected even though the model answers were provided. While it did provide an opportunity to self-evaluate, it is not necessarily the case that all students would have benefitted from this in the same way that they could have if their work was individually corrected or feedback was provided. Given the large number of students registered in the module though, it seems a mammoth task to provide such independent feedback and correction to every student. However it is questionable whether lecturers' one-size-fits-all approach in providing the 'model answer' is helpful to all students. I can surmise that for students who were not able to use the 'model answer' to enhance their learning, it did not help them develop the recognition and realization rules necessary to produce the legitimate text (Bernstein, 2000).

Feedback is a crucial factor in student success as it provides students with information about their misunderstandings and understandings that enhance their learning. The lack of feedback seems to have deprived both lecturer and students of the opportunity to identify and thus achieve the different milestones that evidence learning and to develop appropriate teaching and learning strategies (Hattie, 1999). By this I mean that lecturers potentially lost out on the opportunity to understand their students' academic needs and hence the opportunity to adapt their teaching accordingly. Similarly the opportunity for students to enhance their learning is reduced.

Dickens and Arlett (2009) contend that the quality of student learning is dependent on the quality of teaching. The high failure rate amongst students in the ME module seems to suggest a failure on the part of students to benefit from the learning experience thereby calling into question the quality of their learning experience (Prosser & Trigwell, 1999). It was established in student interviews as well as in the interviews with academics lecturing the module that students were encouraged to rehearse problems and to memorise information. From the data it is clear that students were encouraged to adopt a surface approach to learning, an approach that limits students' opportunity to develop relational understanding and to apply that understanding to new and abstract situations. It appears that the learning environment and the learning outcomes compromised the quality of the learning experience. This could have implications for the student in subsequent modules that rely on understanding and application of the mathematical concepts taught in the ME module (Felder & Brent, 2005; Prosser & Trigwell, 1999; Skemp, 2006). This calls into question the quality of teaching and could provide an explanation for why students adopted the learning approaches they did. Furthermore, Marton and Saljo (1997) claim that the learning approaches which students adopt correlates with the quality of the learning outcome. From the interviews it is apparent that lecturers' focus was on getting students to pass the module and that was clearly envisaged by students as the learning outcome as well.

8.3 Implications for Teaching and Learning

Williamson *et al*. (2003) suggest that a holistic approach, that is a balance between practical applications as well as theoretical understanding, encourages students to adopt deep approaches to learning (Sazhin, 1998). To enhance the mathematical and engineering expertise of engineers, mathematicians need to become familiar with the mathematics that is relevant to engineering and how it will be used in an engineering context (Bickley, 1964). This will provide the opportunity for engineers to acquire an understanding of mathematics from the perspective of engineering.

8.3.1 Framing. The strong framing over sequencing of topics demonstrated in the ME module is important since correct sequencing facilitates the development of mathematical concepts from lower to higher levels of complexity and enables conceptual development (Krathwohl, 2002; Raths, 2002). The analysis revealed strong framing over pacing (F++) which suggests that failure amongst students could potentially be attributed strong framing over pacing as students may not have had the time required to acquire the realization rules necessary to produce the legitimate text (Bernstein, 2000; Morais, 2002). While a potential solution is to weaken the framing over pacing (Bernstein, 2000) this might prove difficult to implement in the ME module given the high volume of work in the given time frames as well as in coordinating the three groups of students to ensure that they complete the required content before each assessment. While it is not an optimal solution weakening the pacing is also an expensive solution (Bernstein, 2000). Morais (2002) suggests that framing over pacing can be effectively weakened by changing the characteristics of pedagogic practice. By creating an intradisciplinary environment, that means by weakening classification between topics within the ME module, concepts are constantly revisited resulting in an increase in the time spent on each section. In the process, conditions for students to progress to more advanced levels of abstract thinking are created (Morais, 2002). Morais argues that this also serves to explicate evaluative criteria, which it has been established enhances the chances of acquiring the recognition rules necessary to produce the legitimate text.

Yet another alternative suggested by Morais (2002), is to weaken the classification over spaces, which results in weakened framing over hierarchical rules. This simultaneously strengthens framing over evaluative criteria while weakening pacing. Weak framing over hierarchical rules effectively creates a favourable environment for students to work together

(Morais, 2002). As mentioned before, certain modalities of pedagogic practice optimize students' chances of success (Bernstein, 200; Morais, 2002). This forms the basis for Morais's (2002) suggestion that teachers be trained to develop the competences required to vary the combination of characteristics of pedagogic practice to achieve the necessary conditions for student success. She indicates that new approaches in pedagogic practice require changes in teacher's ideological and pedagogic principles. The intention is to conscientize teachers about what their pedagogic practice means and what the effects of them are for student learning.

At the SAHEI, the ME module is one of the first mathematics modules whose role it is to induct students into the discipline of engineering. The specialization of 'voice' means "your educational identity and specific skills are clearly marked and bounded" (Bernstein, 1975, p. 81). What is the specialized voice that teaching has produced in the ME module? To determine that I analysed the regulative discourse, which refers to the unintended outcomes (akin to the 'hidden curriculum') that have manifested as a result of the pedagogy. Jackson argues that students must "learn how to learn" in order to be successful and so adapt to the informal rules, beliefs and attitudes that are portrayed. The message that is sent out is that passing the module is the ultimate goal and that it can be accomplished by following the 'recipe', that is rote-learning, practicing assessment-type problems, attending lectures and using the lecture notes, whereas the preferred goal is for students to understand the mathematics. The lack of theoretical underpinning of the content could create the impression that conceptual understanding was not important and could downplay the critical role of mathematics in engineering. The module was presented as though it is a rite of passage for engineering students and not as a critical component underpinning engineering.

8.3.2 Pedagogy. **Understanding mathematics was an important consideration according to the HoS:**

> "Well. We want them to cover the content, make sure that the students understand the content and are able to apply it. I mean that's really what we want from all of the lecturers, whether it's engineering or its science lecturing". (Interview, HoS, 2012)

While Bernstein's concepts of classification and framing examined the structure of the module, other empirical evidence that emerged (instructional practice) was analysed using teachers' philosophical and epistemological conceptions as a framework. This framework provided observable indicators that enabled me to analyse lecturers' teaching styles.

Fitting into the mould. Lecturers privilege an algorithmic, assessment-oriented approach to teaching and learning. Despite the lack of collaboration between the lecturers on issues of teaching and learning, inspection of the data showed that lecturers approached teaching and learning in similar ways. The lecturers adopted approaches that were identified as algorithmic and assessment-oriented. Data collected through observation and interviews suggest that students were presented with a system or a 'recipe for success' which encouraged them to rote-learn and practice assessment-type questions. In addition, it appears that lecturers' focus was to enable students to pass the module: "[it is like] baking a cake. Here's the recipe, here's the ingredients, switch the stove on, you'll get a cake in the end. The approach... that is not for engineering" (Lecturer interview, Dr A, 2012). Be that as it may, Dr A adopted the 'recipe' approach in his lectures despite acknowledging the inappropriateness of this teaching approach for engineering students.

Algorithmic and assessment-oriented approaches to teaching and learning privilege surface learning and strategic learning over deep learning. Data collated from interviews with successful students and the student questionnaire, suggest that students have become savvy in grasping the requirements to pass. This is exemplified in the following statement:

> The system is there you just need to find out your place in the system … if you [are] thrown in the river, if you go against the current you obviously battling and if you go with the current you obviously going to be part of the system. (Student interview, Student B, 2012)

The statement above captures the student's conviction that to be successful he had to become a part of the system. According to the student, the 'system' was attending lectures, using the lecture notes, completing the additional tutorials and mock assessments as mentioned by the lecturers. This indicates that the student acquired the recognition rules as he was able to identify the context (Bernstein, 2000). He also acquired the realisation rules (passive), as is evident in the statement indicating that he had to "go with the current". Judging by his success in the module, he was able to put together the meaning of the context and produce the legitimate text thereby achieving active realization (Bernstein, 2000). In other words (and in the words of Dr A) the student followed the ‘recipe’ successfully. In general, the interview with successful students revealed that they followed the advice of the lecturer, attended lectures and tutorials, completed additional tutorials and mock assessments and worked consistently to pass the module. From the scrutiny of the pass rates of first year students I can infer that the ‘recipe for success’ is selective about who it provides success to as 39% of the first entry first year students failed the ME module in 2012. The overall failure rate including students who were repeating the ME module was 22% in the same year.

Lizzio *et al*. (2002) contend that high volumes of work combined with assessments that measure the reproduction of knowledge, procedural knowledge and mastery of factual information encourage surface approaches to learning. High volumes of work and assessments and tasks that promote memorization and procedures is characteristic of the ME module. The learning environment and students’ perceptions of learning are related to the approach they adopt to learning (Prosser & Trigwell, 1999). In this study students clearly perceived learning in that subject as an accumulation of knowledge, and were more likely to memorise and rehearse mathematical problems from the tutorials and mock assessments. Interviews with successful students showed that they rehearsed the problems from tutorials and mock assessments. Interviews with lecturers revealed that they encouraged students to rehearse ‘assessment-type’ questions through problems provided in the tutorials and mock assessments. According to Prosser and Trigwell (1999) and Lizzio *et al*. (2002) it appears that in this type of learning environment where students perceive the assessment as requiring memorisation and recall, combined with the high volume of work and time frames students were more inclined to adopt a surface approach to learning (Lizzio *et al.*, 2002; Prosser & Trigwell, 1999; Ramsden, 1992). The implication of this lies in the quality of students’ learning which points to them developing a limited understanding of the content since surface learning constrains students’ ability to develop the type of understanding and to engage in the quality of learning required of university students (Prosser & Trigwell, 1999).

The algorithmic approach (traditional) to teaching encourages students to approach ‘learning’ in a systematic way (attend lectures, download notes, do the assessment-type problems). This view perceives teaching as transmitting knowledge from the teacher to students (Koehler & Grouws, 1992) with the student as the receiver of knowledge. Having established that an algorithmic and assessment-oriented approach to teaching and learning is privileged, the question that arises is what type of learning and learner does an algorithmic and assessment-oriented approach to teaching privilege?

The type of learning privileged is conceptualized by various authors as a surface approach to learning (Marton & Säljö, 1976), instrumental understanding (Skemp, 2006) and procedural fluency (Kilpatrick, Swafford & Findell, 2001). The literature shows that rote-learning and practicing step-by-step procedures prioritises instrumental understanding over conceptual understanding (Mayer, 2002). This view is acknowledged by Dr A, who claims that given sufficient examples students can pass the module, but that does not mean they understand the mathematics, and shared by Young (2006), who says that programmes which emphasise key skills over conceptual understanding are not academically sound. These approaches to learning are generally a consequence of algorithmic approaches to teaching.

The ME module should provide the fundamentals needed in other modules. However, lecturers claim that students learn mathematics sufficiently to pass the module implying that they develop an instrumental understanding of mathematics. This means that the opportunity to develop conceptual understanding is reduced. The 2011 and 2012 data obtained from the SAHEI database supports this claim as the total throughput rates across the ME and the subsequent mathematics module in first year for 2011 and 2012 are nearly 15%. If the fundamental concepts in the ME module are not acquired, conceptual development is likely to be constrained, and this by extension inhibits the development of problem solving skills. This implies that students can reproduce what they have learned, albeit instrumentally, but are not enabled to think and work independently. I can infer that students pass the ME module because they have been well-coached and thus have rehearsed the examination-type questions well. This does not prepare them to be independent thinkers and workers which is a skill that an engineer requires as well as being one of the exit level outcomes stipulated by ECSA. Students who pass the module are not necessarily able to apply what they have learnt. Furthermore it entrenches Grossman’s claim that rote-learning affects the longevity of knowledge retention (1984). The engineering degree is a professional degree that demands knowing what, when and where to effectively apply knowledge of the content. A transmission approach may not necessarily provide the opportunity required for the development of such skills.

According to the literature (Case, 2000; Marton & Säljö, 1996; Ramsden, 1984), surface learning has several consequences. The first is that it reduces the students' ability to apply what has been learned to new situations (Mayer, 2002). I can infer from the following statement made by a lecturer in engineering: "What are you teaching these students, they don't know how to apply?", that students who pass the ME module are not able to apply this knowledge in subsequent engineering modules (Interview, Dr A, 2012). Secondly, surface learning deprives students of the opportunity to make the connections between existing and new knowledge which would make new knowledge more meaningful (Grossman, 1986).

Surface learning seldom enhances the development of conceptual understanding (Krathwohl, 2002; Skemp, Hiebert, Marton, Raths, 2002). Teaching students step-by-step procedures without a theoretical understanding of concepts impedes long term retention of knowledge (Grossman, 1986; Seymour, 2000). This was corroborated by one of the successful students who when interviewed said that despite passing the ME module he had difficulty in the subsequent mathematics module for engineering students (Student interview, Student A, 2012) and by lecturers who acknowledge that students only learned the mathematics sufficiently to pass the module.

Although learning by rote is a construction in itself, when encouraged as the only means of learning it denies students the opportunity to think and learn in a meaningful way (Grossman, 1986). This is significant because meaningful learning leads to the acquisition of knowledge and the development of cognitive processes that are necessary for the development of problem solving skills (Mayer, 2002; Krathwohl, 2002). Since the development of problem solving skills is an outcome of the module (ELO 1), meaningful learning should be encouraged and promoted through pedagogic practice (Mayer, 2002). Furthermore, surface learning stifles the opportunity for students to develop divergent and creative thinking, which are both attributes required of engineers.

Students were encouraged to learn the procedures rather than develop conceptual understanding: "we will mark the method … based on your wrong equation … in fact you can get all your answers wrong … [and] arithmetically get 90%" (Observation, Dr B, 2012). The above statement can create the impression amongst students that it is acceptable to use the incorrect method as long as the answer is worked out correctly, this advantages procedural fluency over conceptual understanding. However once these students become practicing engineers, choosing the incorrect method can have dire consequences. This brings into question the focus on passing the module without little opportunity to develop an understanding of when it is appropriate to use certain mathematical methods and why. Learning what to do without knowing why to do it does not necessarily lead to the development of conceptual understanding. Ramsden (1984) claims that the university teaching context could result in unforeseen consequences for learning by discouraging students from understanding the basics in favour of tricks and strategies to pass examinations. This was evident in Dr B’s lectures when he encouraged students to “write down this list off by heart [referring to formulae] … and I guarantee …the method you have not used yet is probably the method you have to use”. While the intention of the lecturer may have been to show students how to identify the correct formulae by the process of elimination, it does not enable students to understand why the use of that specific formula lends itself to the solution of the problem. The learning opportunity for understanding why the formula is applicable is lost constraining the opportunity for students to transfer that knowledge to new situations.

As presented in Chapter Three, Marton and Säljö (1976) state that the approaches students adopt to learning are based on the task at hand and that students act in response to a situation as they perceive it to be (Ramsden, 1984). Case (2000) concurs stating that students adopted deep, surface and strategic approaches to learning based on what they perceive the educational situation as demanding. In this ME module, all three lecture groups of students were exposed to an algorithmic style of teaching and were encouraged to practice typical test and examination problems (assessment-oriented). In addition, students were encouraged to ‘know’ and ‘by heart’ the rules, definitions and formulae.

8.3.3 ‘One-size-fits-all’ approach. The ME module privileges a ‘one-size-fits-all’ curriculum with an instrumental approach to teaching. An algorithmic way may work for some students but not for all students. The students registered in the ME module form a diverse group of students with different learning styles, and educational backgrounds and are from different social classes. This calls for a variety of approaches to teaching and the type of assessments that are provided. Students with different learning styles may benefit from a variety of teaching and assessment approaches which cater for their differences. The ‘one-size-fits-all’ is ironical in light of the diversity of students in terms of their socio-economic and educational backgrounds and their individual learning styles.

This is further compounded when one considers that, globally, higher education is faced with the challenge of mathematically under prepared students entering their portals. Finally it was pointed out that all students might not respond equally to the teaching by transmission approach and that some students will inevitably be disadvantaged over others. Dr A acknowledged that if students followed the ‘recipe’ (lectures, notes, additional tutorials, mock assessments) it should be easy for them to pass the module but: “it doesn't seem to be the case. I don't know what's the problem” (Lecturer interview, Dr A, 2012). Clearly the 61% pass rate amongst all first year students in the ME module indicates that the algorithmic approach was not successful for all students. Having clarified that the approach to learning was algorithmic and encouraged practice and rote learning, a discussion of the implications for learning is presented next.

Students who are successful in the ME module can be viewed as acquirers since, according to Bernstein (2000) they have acquired the recognition and realization necessary to produce the legitimate text. The successful students, say Bernstein, are labeled by lecturers as ‘conscientious’, ‘attentive’ and ‘receptive’, terms that I found to be synonymous with those used by lecturers in the interviews, that is: ‘hardworking’; ‘listen’ and ‘bright’ (Lecturer interviews, 2012). Bernstein asserts that students who are not successful are described as ‘not listening’, a label synonymous with those used in lecturer interviews: ‘not very diligent’, ‘use an algorithmic approach’ and ‘lazy’. The selection of content is downward since those in authority control what is taught. According to Hugo (2013) this means that the society this reflects is one that favours structure and fears corruption. Since selection of the content does not appear to be largely within the control of the lecturers and certainly not within that of students, it is difficult for lecturers to know and to understand what the mathematics content should prepare students to do and how it fits into the concurrent and subsequent engineering modules. In addition, the selection of content which is purely mathematical, suggests that the mathematical knowledge determined by the mathematics department is of most worth in the ME module (Hugo, 2013).This certainly points to the question alluded to by Bickley (1964), that is, whether the link between mathematics and engineering at the SAHEI is left to the engineering lecturers to illustrate.

8.3.4 Assessment. Assessments were analysed using Bloom’s revised taxonomy to determine the cognitive demand of the questions, the quality of final examination questions and the alignment between mathematical tasks and assessments. At the SAHEI, assessment provides a framework within which the effectiveness of teaching and learning can be measured (Shay & Jawitz, 2005). ECSA, the statutory body that is responsible for the accreditation of engineering programmes in higher education, stipulates that “each outcome specified … must be explicitly addressed in terms of the means of assessment and the criteria for satisfaction of each outcome at exit level. The choice of evidence and format of presentation is left to the academic identity” (ECSA, 2002). Although the curriculum document clearly states that the module aims to build towards the achievement of ECSA ELOs 1, 2, 5, 6 and 9, I did not find evidence in the lectures and tutorials that I observed that achievement of the ELOs was a focus of instructional practice. I can infer from this that the ELOs are included in the curriculum document to satisfy the ECSA requirements.

Formal tests and examinations are the sole means of assessment, which means that assessments advantage students for whom tests are the preferred form of assessment. Rust claims that summative assessments do not add value to student learning (Rust, 2002). When formal tests are the only means of assessment, it implies that the diverse student profile is not considered alluding again to the one-size-fits-all approach that is the privileged approach adopted in this module. It is evident, given the ‘one-size-fits-all’ approach, the algorithmic and assessment-oriented teaching, the ‘system for success’ that a certain type of learner is envisaged. That means that the type of learner who responds well to teaching and learning activities that require rote learning, rehearsing problems, following rules and reproducing work regarded as the legitimate text, is thus privileged. E-mail communication from the deputy dean, Dr DN, indicated that the ME module is required to show some progress toward the achievement of the ELOs (e-mail communication, Dr DN, 2012) and assessments therefore do not assess whether students have acquired the ELOs. The implications of not knowing whether students have acquired the ELOs may have consequences for them in subsequent modules within the engineering degree curriculum as it is uncertain whether the foundation on which the ELOs are to be built will be in place.

The quote below confirms a student’s perception that, “the mock exam is the exam itself … they change … the numbers and values so if you do the mock exam you will definitely pass the exam” (Student interview, Student F, 2012). ECSA requires “course handouts and examination papers [and] the exact procedure we go through moderation of exams and marking of examinations” (Interview, HoS, 2011) in the accreditation process. This suggests that the final examination is deemed to be the true test of the quality of learning. Bloom's revised taxonomy was used to evaluate the quality of the final examination questions as the evaluation of this falls outside the scope of Bernstein's theories. The analysis revealed that the final examination questions were mostly on the level of *apply* which means that higher order cognitive skills were assessed in the final examination. However a comparison of the questions in the final examination and those in the mock examination showed that the questions were the same with differences in the numerical values. This means that the final examination questions were well-rehearsed (captured in the excerpt above) thereby reducing their cognitive demand. As such the final examination questions were not novel, placing them on the level of *apply* (execution) as a routine procedure and not at the level of implementation which would imply a novel problem (Chapter Seven). This raises the concern about how well students who passed the module learned the mathematics?

What stands out is that lectures, tutorials and assessments on the one hand were well-aligned to lecturers goals of enabling students to pass the ME module. This goal differs from that of the ME module which aims to provide students with a basic understanding of mathematical concepts and application in physics, geometry and engineering contexts.

8.4 Rationale for the Teaching Approach

The third research question asked why teaching and learning in the ME module is approached the way it is and in particular what beliefs do academics have about teaching and learning mathematics to engineering students? In this section I describe lecturers' teaching styles and their rationale for the ways in which they approach teaching and learning. Teachers' philosophical and epistemological conceptions were used as a framework to analyse lecturers' teaching styles and the reasons for their teaching decisions. The academic freedom to research and teach as well as the common sense approach to teaching is sanctioned by the HoS as evidenced in the excerpt that follows:

> we don't …prescribe …to our staff whether they are teaching engineering students, [or] science students … we expect them to know what they need to do to lecture in engineering. It is largely handed down from one lecturer to the next … This is especially so when we have pure mathematicians teaching and they really want to go

> into all the details of the proof and the abstraction which we say is good but there is a limit to how much you can have. (Interview, HoS, 2012)

The first research question provided insight into the role and relevance of mathematics in engineering while the second research question showed that the ME module is strongly classified and framed and that the teaching styles of all three lecturers were algorithmic and assessment-oriented. Evidence collected from interviews, observations and the student questionnaire were used to answer the following research question: Why is teaching and learning approached the way it is? The construct of beliefs was used to determine lecturers' beliefs about mathematics for engineers and teaching and learning mathematics in an engineering context. There are several factors that emerged from the data as possible reasons for the teaching and learning approach evident in classrooms. These include: beliefs about mathematics for engineering students; beliefs about teaching mathematics to engineering students, beliefs about students and learning, teachers goals in the ME classroom the lack of theoretical underpinning in the ME module, teachers knowledge of the relevance of mathematics in engineering and the strong classification and framing of the module.

8.4.1 Beliefs about mathematics for engineers and beliefs about students influenced how teaching and learning was approached. In this study, it was found that lecturers distinguished between pure mathematics and mathematics for engineers. Dr A viewed the ME module as an applied mathematics course which was used to explain reality and emphasised applications. Dr B indicated it was a tool to solve problems and Dr C concurred with this saying it was to solve problems in the world. The consensus was that mathematics was a *tool* that could be applied to solve problems. Generally all three of the lecturers agreed that students were capable of doing mathematics albeit within certain time limits. Dr A responded that given sufficient time, students could achieve the mathematical competencies required of them but that in the ME module, time was not sufficient. That was corroborated by Dr C, speaking in the context of undergraduate students: "it's a fast process … if there's no time limit then everybody can most probably do it. Under the [given] time constraints they [all] can't do it but it requires a lot of practice which is then the sort of nurturing type thing"(Lecturer interview, 2011). In the interview, Dr B concurred that mathematics ability was innate and acknowledged that students could do mathematics "to a certain degree … and then each one's got to be helped. Each one's got their own limit … it's just … how you're made".

Dr A claimed that students failed because of their inability to understand mathematics due to their lack of high school mathematical competencies. Dr B said students did not make an effort while Dr C reflected in the interview that one of the reasons why students failed was because “they want to understand and I say the simplest, you can't understand, it's taken hundreds of years to evolve you just got to apply the stuff understanding sometimes comes years later when you mature”. In addition he claimed that students failed because they did not rote learn and practice, attend lecturers and tutorials or make an effort to do their own work. His use of the transmission approach can be attributed to his belief that students could not understand the mathematics and therefore had to learn it off by heart and had to practice. He thus taught in a way that encouraged rote learning and practice. While some of the literature showed that beliefs play a significant role in influencing how teaching and learning is approached in the mathematics class (Ambrose, 2004; Foss, 2000; Hersh, 1997; Raymond, 1997; Stipek, Givven, Salmon & Macgyvers, 2001; Thompson, 1984), there are other studies that show that this is not always the case (Boaler, 2000; Burton, 1988; Hoyles, 1992; Skott, 2001). The latter studies show incongruence between teachers’ espoused and enacted beliefs. It also shows that there are contextual factors that influence how teaching and learning is approached.

Relevance of mathematical concepts in engineering context. Dr A claimed that in the ME module application was not emphasised although he sometimes attempted to show how Mathematics, Applied Mathematics and Physical Science were interconnected. However, while that may be true often the applications did not relate to the mathematics presented in the lecture. Time constraints emerged as the most common reason for mathematics being taught without showing the application of it in relevant engineering contexts. Dr A indicated that it was not possible to teach this way all the time as it was time consuming. Hence the algorithmic approach that he followed could be attributed to the volume of work, tight time frames and meeting test dates. On the other hand, Dr B did not seem to be clear on where the mathematics was relevant in engineering thus providing a reason for why he did not show the application of mathematics in relevant engineering contexts. He also acknowledged that there was a lot of work but not a lot of time available to show students the application of mathematics in engineering. Dr C indicated that mathematics was applied in physics and chemistry but acknowledged that time constraints did not permit elaboration of this during lectures and tutorials.

Theoretical underpinning of mathematical concepts. Lectures seem to recontextualise the mathematics in the ME module at the level of the classroom based on their beliefs about the role of mathematics in engineering. From the interview data and the CoAES handbook (2012), I can infer that legitimate mathematics knowledge for pure mathematics requires theoretical understanding and therefore includes proofs of theorems. The evidence suggests that the legitimate mathematical knowledge privileged for engineers is being able to reproduce the rules, formulae and definitions and show mastery of procedures. Dr A constantly reminded engineering students in lectures “remember in this course we don’t teach you theorems, we teach you applications” (Lecture observation, Dr A, 2012). The lack of mathematical proofs, theorems and theoretical explanations in the ME module meant that students were exposed to the content without a theoretical understanding of it. Teaching content without the theoretical underpinnings may lead to instrumental teaching (Mayer, 2002). From my understanding, the lack of theoretical underpinning (and proofs) in the ME module may have made it difficult to present the content in a way that encourages conceptual development as it would have been challenging without the theoretical basis necessary for the development of conceptual understanding. This suggests that lecturers teaching approaches may have been influenced by the lack of proofs in the content of the ME module.

Implications of instrumental teaching. The perception created is that engineering students are not required to develop theoretical understanding of mathematics or to know mathematics to the extent that science students do. This creates the impression that it is not important for engineers to understand the mathematics they will use in practice. I can infer from this that the intrinsic and aesthetic value of the ME module is thus reduced for engineering students.

Own experiences. A lack of educational background can lead to lecturers teaching from their own experience of being taught mathematics which can strongly influence their teaching style (Timmerman, 2004). Often approaches to teaching and learning are informed by lecturers’ experiences of being mathematics students themselves as supported by the literature which suggests that teachers are likely to teach in the ways that they were taught (Ball, 1990). Dr A and Dr B acknowledged that they used methods and materials from their days as students. This is supported by data collected during interviews and observation of lectures where Dr A indicated that most of the examples he used in lectures were from his notes when he was a first year student (Lecture observation, Dr A, 2012). Dr B told students in the lecture: “Now I did one way at school, [the method he was demonstrating] but … you don’t have to do it my way” (Lecture observation, Dr B, 2012). Another reason provided by Van de Walle is that teachers adopt an instrumental approach to teaching is that they may not fully understand the theoretical underpinning of mathematics themselves and in such cases the algorithmic approach is the easiest way to teach (Van de Walle, 2004).

Goals. The data shows that lecturers’ goals were to enable students to pass the module. The focus on passing the module could have motivated teaching in a way that they believed would achieve this. From the evidence it is clear that this meant adopting an algorithmic, assessment-driven approach which provided numerous typical assessment-type problems for students to practice. Students were also encouraged to rote learn and practice formulae, rules and definitions.

The institution is under constant pressure from the state to improve retention and graduation rates. This combined with an under prepared student cohort, with diverse educational backgrounds meant greater challenges for the teaching and learning process in the current higher education context (Fisher & Scott, 2011). The increasing demands placed on lecturers without adequate support for the teaching and learning process can lead to teaching in a way that provides the best opportunity to improve the pass rates. This seems to be exactly the case at the SAHEI since the goal of lecturers is to get students to pass the module and the resultant, according to lecturers, are students who learn mathematics well enough to pass the module. The approach identified is algorithmic and assessment-oriented, in other words it is a well-rehearsed module with little chance to fail if the system is followed. While the pass rates in the ME module paint a picture of success, the throughput across the first year, including the ME2 module, suggests a different story, one that is not quite as successful as the pass rates in the ME module.

Cascading this down to the ME module, this means ‘doing what it takes’ to maximize the number of students who pass the module. To enable that goal to be achieved, students are subjected to a ‘recipe for success’ or a ‘system that works’. However that system does not work for all students, as evidenced by the failure rate and the total throughput in both mathematics modules in first year. Those students, who in the first instance may not recognise the ‘system’ or ‘recipe’ (recognition), and in the second, may not have grasped what to do (passive realization) or how to implement it (active realisation). The ‘system’ provides one way of approaching teaching and learning which according to Fisher and Scott (2011) might suit the learning styles of some students but not all.

Alignment and assessment. The findings show that lecturers’ goals in the ME module were to get students to pass the module. Since assessments were the sole means of evaluating students, all teaching and learning activities (lecturers, tutorials and mock assessments) were designed to build towards the assessments, in other words to mould students into the kind of learner that is required to pass the module. Bloom’s revised taxonomy was used as an analytical tool to determine the quality of the final examination questions. Additional tutorials, mock assessments and assessments were also compared to determine the alignment between the various activities in the module which lead to final examination. The analysis of the final examination questions showed that they were mostly on the level of Apply. However a comparison between the final examination questions and mock examination questions as well as mock tests and tests show that the test and examination questions were well-rehearsed. This was acknowledged by lecturers and students and means that all the questions in additional tutorials and mock assessments are the same with changes in numerical values in the tests and examination. This also aligns with the HoS’s statement and that of Dr C, that lecturers test what they teach:

> So when you set the test you will base your test questions on similar story problems. … there has to be a strong connection between what you do in lectures, tut problems and test problems … otherwise it's pointless … and I make sure that you’ve got your lectures , the textbook. You emphasise this is a typical problem, you make sure it's in the tut and then when we set the test it's the same so I think it is very important … it might be too artificially constructed but that's the purpose, you know… so it's not a surprise giving them that in the test. (Interview, HoS, 2011)

Students were viewed in a deficit light. It was evident that students were considered from a deficit point of view. Lecturers claim that a strong school background is necessary for successful participation in the ME module. Dr A indicated that the lack of high school mathematical knowledge was a setback as he constantly had to re-visit mathematical concepts that students should have been familiar with from high school but were not. He acknowledged that he lapsed into periods of algorithmic teaching, as the time he would have spent showing the application of mathematics in engineering contexts was used in re-teaching high school mathematics concepts. Hence having to re-teach high school mathematics in addition to the already heavy workload is a contributing factor to his approach to teaching and learning. Dr B concurred stating that he had to teach the students mathematics that they should have done in high school and that it took time which was needed to do the course work. All three of the academics teaching the mathematics module agreed that one of the key challenges in the ME module was the lack of high school mathematical competencies that students are expected to have in place when entering the engineering degree programme. This indicates that lecturers who were teaching in this module were aware that many of the students entering the engineering degree programme for the first time, lack the mathematical background necessary to facilitate their learning in the ME module.

Lecturers' were asked to describe the students in their lecturer groups. Their description includes large student numbers, lack of high school mathematical knowledge, lack of ability to do undergraduate mathematics, dependent and had no confidence. They claimed that factors responsible for student failure were lack of high school mathematical knowledge, not grasping the module requirements, not following lecturers' instructions and lack of effort. Dr A, Dr B, and Dr C claimed that students lacked fundamental mathematical competencies that they were expected to have acquired in high school and which they were required to know at university level. Both Dr A and Dr B claimed that much time had to be spent teaching students the mathematical concepts that they should have learned at high school. To overcome the problem of under prepared students, valuable time was spent teaching sections that were not covered in high school. This impacted on how lecturers approached teaching and learning. According to Dr A, if they did not have to teach the high school sections they would have time to "teach differently [and] also show applications. I don't have time for that now ... I just go through the fundamentals" (Lecturer interview, D A, 2012). Dr B also explained that attempting to address the lack of mathematical competencies in tutorial sessions was problematic because there were students who required assistance with the content of the ME module, making it a challenge to assist all the students given the time constraints. Furthermore, Dr A stated that the reason why students failed was "just their inability to understand mathematics" which he attributed to the lack of mathematical competencies and the short time frames. Dr A and Dr C agreed that given sufficient time students could pass the module. However the pacing of the module was strongly framed to enable the completion of the syllabus which means that students could not be given the time that they required to learn the content. The lack of mathematical competencies, combined with the high volume of work, and strong framing over pacing are factors that potentially motivated an algorithmic approach to teaching. The lack of mathematical competencies meant that students would not have in place critical building blocks required to make connections between existing knowledge and new knowledge.

Mathematics ability. Dr B on the other hand felt that mathematical ability was innate and that students had to ‘do’ the problems if they wanted to pass. Dr C expressed his belief that students wanted to “understand and I say … you can't understand, it's taken hundreds of years to evolve you just got to apply the stuff, understanding sometimes comes years later”. He indicated that not all the students had the ability to do the mathematics required in the time frames that were given. Thus he believed that the best way for students to pass the module was for them to rote learn the rules, formulae and definitions and to practice assessment-type problems. This provides a possible justification for why Dr C adopted an algorithmic approach to teaching in the ME module.

Effort. Dr B’s comment that “their [students] lack of competencies, they can get that up to scratch by the time of the exam if they just sit and work”, suggests that apart from ability, students needed to make the effort to ‘catch up’ and that many of them did not. Dr C concurred that lack of effort was a problem, saying that students were lazy and did not put in the effort that was required in the module. The expectation is that everything that the student requires to pass the module is provided and therefore the reason for failure must have something to do with the student.

The approach to teaching and learning was algorithmic, in other words lecturers were promoting a ‘recipe for success’. There was little consideration for differences in educational background, language, learning styles. The focus was on completing the ME curriculum in terms of the content, teaching and assessment. Basically it was managed as though it were a ‘pipeline to success’. Lecturers conveyed a deficit notion of students and used this as a rationale for why students were not successful in the module. What did not come through were lecturers’ own efforts to provide a teaching and learning environment that would cater for differences in learning styles and inadequate mathematical competencies.

Helplessness. What comes through very clearly in the data is the feeling of helplessness faced by the lecturers who were pressurized into improving the retention rates, with large numbers of students of varying abilities and mathematical competencies. Dr C indicated that the competencies of students were 'just all over the place' and whilst those who had the competencies would pass with practice those with poor backgrounds (mathematical) would "stumble because their previous knowledge is not sufficient and they can't work with fractions, they can't do mental arithmetic things like that stumble them so they prevent them from carrying on. So they get blocked". He indicated that they (lecturers) tried "to fix it and cannot really fix it because there are so many different things". Dr C indicated that "we have shoved them all into one class ... all the same. But eventually they do [pass] you know. If you get a good pass rate then something has happened but there are those who are just left behind".

8.4.2 Contextual factors and personal theories influence how teaching and learning is approached. The module schedule, goal of passing the module were found to be some of the factors that influenced how teaching and learning was approached.

Module schedule. Since all three groups had to write the same examination it made sense that in order to ensure fairness to all, they wrote the same tests, did the same tutorials and covered the same content. Scheduling of tests had to be done meticulously as all 667 students in the three groups had to be accommodated for the tests at the same time. Accommodating the large cohort of students was compounded by having to consider the schedule of students repeating the module, some for the second time. This meant negotiating the timetables of students who were registered for modules in first, second and sometimes even third year. This necessitated meticulous planning on the part of the module coordinator to ensure that the content was divided such that it could be completed in thirteen weeks, that all three groups completed the same sections in the given time and that all groups of students had exposure to the same preparation for test and examinations (tutorials, mock assessments and access to lecture notes and hints on the website). That meant ensuring the selection of content, sequencing of topics and pacing had to be clearly outlined in the module schedule. Above all every attempt was made to ensure that students were not disadvantaged. Hence the context within which the module was implemented called for radical organisation of the module leaving little room for individual lecturers and students to negotiate issues of selection, sequencing, and pacing of the content. This resulted in the ME module being very strongly framed in terms of selection, sequencing, pacing and evaluative criteria.

The strong framing of the module was to ensure that lecturers and students completed the required amount of work per week. The pressure of keeping to the module schedule seems to have resulted in the fast pace of lectures and could be one of the reasons why the algorithmic approach was the privileged approach to teaching and learning. That was corroborated by lecturers who stated that they had no time to teach differently. The strong framing contributes to a fast paced lecture to incorporate the high volume of work in the given time constraints. This warrants teaching methods that ensure the fast transmission of content. Grossman (1986) says it is less time-consuming to teach by transmission especially since large volumes of content can be delivered quickly and systematically thereby facilitating easy delivery of large volumes of content in ‘easily-digestible’ pieces, which are also complemented with resources (lecture notes and website) and activities (additional tutorials, mock tests and mock examinations). The transmission model has its own set of advantages and disadvantages depending on the goal. The transmission approach is advantageous in terms of enabling lecturers to complete the required amount of work in time so that students can sit for the tests and the final examination. On the other hand, the literature clearly shows that teaching by transmission has its disadvantages (discussed earlier in this chapter) as it encourages rote learning and instrumental understanding. While memorization and instrumental understanding have their place in the learning process, the literature shows that it is not academically sound for it to be the sole means of learning (discussed under surface learning earlier in Chapter Three).

The strong framing meant that lecturers had predominant control over the teaching and learning process. Assuming control over all aspects of pedagogic practice allows the lecturer to ensure that work is completed according to the schedule. Generally, in traditional lectures, students are viewed as passive learners and are encouraged by an approach that promotes retention and regurgitation of content, mastery of skills and memorization of rules (Grossman, 1986). That was evident in the teaching and learning approach where students were encouraged to rote-learn and master mathematical procedures. In addition, assessments were well-rehearsed versions of additional tutorials and mock assessments further entrenching the view that students were viewed as passive receivers of knowledge, a view associated with traditional perspectives of teaching and learning. The type of learner envisaged by proponents of the traditional approach to teaching and learning, contrasts with the engineering graduate envisioned by ECSA.

Given the strong alignment between lectures, tutorials and assessments, indications are that most students should have passed the module. However the failure rate amongst first attempt first year students in 2012 was 63%, suggesting that there were other factors that may have contributed to student failure. It could be inferred that the modality of pedagogic practice which in theory should have led to success, did not lead students to acquire the recognition and realization rules necessary for a successful experience. One of the reasons already suggested is the strong framing over pacing discussed earlier which may not have been sufficient to enable students to acquire the legitimate text (Bernstein, 2000; Morais, 2002). This suggests that given the organization of the module in terms of its classification and framing and the congruence between lectures, tutorials and assessments, one of the factors that can be attributed to student failure is the issue of student agency. This will be discussed later in this section.

Students learn mathematics sufficiently to pass the module. The final research question sought to determine how well students learned mathematics. The evidence collected intimates that students learn mathematics sufficiently to pass the module. When asked how well future engineers learned the mathematics in the ME module, all three lecturers agreed unanimously that students only learned the mathematics sufficiently to pass the module. Excerpts from interviews with the lecturers in the module verify this. Dr A corroborated this in the interview saying “to pass! You can ask the other lecturers and you'll find that people are complaining, … so they just learn to pass the maths exam”. Dr B responded saying “I think they just learn it to pass … most of them it's just to get the grades” (Interview, 2012). Dr C corroborates this in the following excerpt: “I think they only learn it sufficiently to pass the module” (Interview, 2012). Students who passed the ME module and were registered for the second semester first year mathematics module indicated that their knowledge of mathematics was still not very good: “Still I'm in the second semester I'm not good at maths still” (Student interview, Student B, 2012). The final pass rates for the ME module as well as the Table 8.1 below illustrates the pass rates for first attempt students in the first and second Mathematics modules over the period 2011to 2012. The module exhibited a 78% pass rate with approximately 61% of first year students passing the ME module. These results on their own suggest that the module was highly successful in improving the pass rates from 2011, which is alarming in view of the fact that the overall throughput of students in both the first and second mathematics modules for engineering students in 2011 is almost 15% while the total throughput for 2012 is just over 15%. This means that only 25% of all students who passed the ME module in 2012 also passed the subsequent mathematics module in the first year. These statistics allude to how well future engineers actually learn the mathematics in the first mathematics module. In this case, it seems that they learn it sufficiently to pass the ME module. The total throughput rates for the 2011 and 2012 cohorts are illustrated in Table 8.1.

Table 8.1

Total Throughput Rates for 2011 and 2012 Cohorts

Year	No.Wrote	Passed ME on first attempt	Passed ME module & subsequent first year mathematics module on first attempt
2011	873	369	128 (15%)
2012	667	410	102 (15%)

I used data from lecturer and students interviews to determine how well future engineers learn mathematics. In their response to the question: How well do you think students learn the mathematics that they require for engineering?, all the lecturers unanimously responded that students learn mathematics sufficiently "to pass the maths exam" (Lecturer interview, Dr A, 2012). Dr A said that passing the module did not mean that students understood the mathematics and Dr C stated that "understanding sometimes comes years later". Dr A claimed that a reason for that may be that the intention of the students was to "pass maths ... not to learn mathematics".

Implications. Students are not able to transfer knowledge to new contexts (Bloom) as the basis for the development of conceptual understanding is not there (Mayer, 2002). This serves as an obstacle to further modules in mathematics and those that are highly math-reliant and further curbs potential to pursue study in traditional and emerging fields (ECSA). This also calls into question students' potential to adapt to advances in technology and in interpreting mathematical data in the field of practice (Bickely, 1964; Sazhin, 1998; Henderson, 2003; Blockley, 2007). There appears to be a mismatch in the way mathematics for engineering students is conceptualized and taught. I can surmise that the stance taken by the mathematics lecturers is neither benefitting nor preparing learners for how they need to know and apply the mathematics in engineering. The lack of mathematical understanding is likely to lead to a lack of mathematical know-how. The lack of applications in relevant engineering contexts leads to mathematics being disconnected from engineering. It seems that in accord with Bickley (1964), the ME module does not appear to prepare students adequately to applying the mathematics in further engineering modules or in the field of engineering practice.

Given the South African context the national imperative is to increase the number of engineers, particularly Black and female engineers most of who come from historically disadvantaged communities. The call from the professional body (ECSA) and industry for what the graduate can do in addition to what a graduate knows has influenced a shift in curriculum that privileges graduate skills. This shift in thinking has in many instances been associated with ‘progressive’ teaching learning approaches, most of which are learner-centred. The current most commonly used approaches emphasise the use of problems which highlight the relevance of mathematics to engineering and the integration of content between modules and encourage the development of the graduate skills required of practicing engineers. According to the literature, engineering education should shift toward teaching and learning strategies that are associated with weak framing over selection of content, sequencing, pacing and evaluative criteria such as PBL and Project-based learning (weak classification and framing). However, weak framing, as argued in Chapter Two, which is said to be beneficial to teaching and learning, does not necessarily favour traditionally disadvantaged (working class) students in the teaching and learning environment (Bernstein, 2000; Case, 2011; Muller, 1998). So while Veldman *et al*. (2008) indicate that engineering education cannot afford not to use PBL as an approach in engineering education, given the debate around teaching and learning approaches that embrace a weak classification of content and a weak framing of pedagogy and considering the background of the majority of the students, a more pertinent question is: can the SAHEI afford to use PBL as an approach in engineering education?

From Bernstein’s argument concerning working class students, it would seem that the status quo, that is the strong classification and framing, would serve to advantage traditionally marginalised students. However an examination of the pass rates indicates that this does not appear to be the case. So if, according to Bernstein (2000), strong classification and framing should advantage disadvantaged students, why is the failure rate still high in the ME module and the subsequent mathematics module? I can infer that perhaps the lack of theoretical underpinning in the mathematics taught contributes to failure amongst students since the opportunity for the development of conceptual understanding and abstract understanding is reduced.

8.5 Conclusion

In this chapter, the role and relevance of mathematics in engineering was established. A summary of the findings from the analysis of teaching and learning (based on the theoretical frameworks: pedagogic device; teachers epistemological and philosophical conceptions and Bloom's Revised Taxonomy) in the ME module was presented. Based on the teaching approaches adopted, the implications for learning of mathematics in the ME module were discussed. The next and final chapter, Chapter Nine, presents recommendations and implications for further research.

Chapter Nine
Implications and Recommendations for Practice

The literature pointed to the changing landscape in higher education and in engineering education. With advancements in technology and globalisation, the 21st century requires engineers to be mathematically competent, not only in applying mathematical procedures, but also in interpreting the results of mathematical solutions. The findings show that mathematics is crucial to the study and practice of engineering and that teaching and learning in the mathematics module are approached in an algorithmic and assessment-oriented way. In addition the research indicates that teachers epistemological and philosophical conceptions as well as contextual factors influence how teaching and learning is approached in the ME module. After consideration of the literature in the field of mathematics and engineering education and the data collected from the research conducted, the following recommendations have been made for the enhancement of teaching and learning in the ME module. The recommendations include improving collaboration between mathematics and engineering academics, encouraging lecturers to make use of the induction modules which provide exposure to theories of teaching, learning and assessment and the restructuring of tutorials and assessments.

9.1 Greater Collaboration Between Mathematics and Engineering Departments Would Lead to Greater Coherence

The analysis of the pedagogic device focused on recontextualisation, singulars and regions and classification and framing. The recontextualisation of knowledge resulted in the lack of proofs at the level of the PRF and the omission of theorems and the section on Elements of Logic at the level of the classroom thereby weakening the integrity of the mathematics offered. Furthermore the identification of the ME module as a region in itself reflects that the module is clearly a site for conflict and struggle. That is so because ownership of the pedagogic device lies with the discipline of mathematics while the module services the discipline of engineering. The struggle over the device is evident in the HoS's decision that the department of mathematics will control what mathematics is to be included and how teaching and learning will be approached. Be that as it may, the discipline of engineering has in the past influenced the content in the ME module and is currently attempting to exert some control over mathematics, albeit without the school of mathematics as part of the discussions. The lack of dialogue between the two disciplines is thus evident and the consequences of it are seen in the struggle over the pedagogic device.

Collaboration between the disciplines of mathematics and engineering may facilitate dialogic communication between the two thereby enabling discussion on issues of content and approach. Engendering liaison between mathematics and engineering academics may initiate ongoing dialogue relating to the enhancement of the ME curriculum. That the ME module is a region, further enhances the need for academic staff to understand it as a module that includes knowledge from the academic discipline of mathematics which is required to be used in the field of practice of engineering. That requires lecturers to have an understanding of how the knowledge of mathematics is to be known, understood and applied in engineering practice, in undergraduate engineering modules and in postgraduate study. Furthermore, the role of mathematics in engineering and the reciprocal relationship between mathematics and engineering, that is the role of mathematics in perpetuating progress in engineering and that in turn advancing progress in mathematics, must be understood for a constructive relationship to be developed. A dialogic relationship may also facilitate the role of the disciplines in producing research that adds to the knowledge base and feeds into the institution's goal of being a research led institution.

The findings of the study suggest that in the implementation of the curriculum, mathematics is taught in isolation to engineering. Authors who have written in the field of engineering education claim that legitimate mathematics knowledge includes tasks that show the relevance and application of mathematics in engineering contexts (Alpers, 2010; Bickley, 1964; Bordogna *et al*., 1993; Craig, 2010; Felder *et al*., 2000; Henderson & Broadbridge, 2007; IMA, 1999; Klingbeil *et al*., 2004; Sazhin, 1998; Williamson *et al*., 2003). Young (2008) claims that finding the balance between theory (proofs and theorems) and showing the relevance of mathematics in engineering (practice) is necessary. This can be accomplished if, as Bickley (1964) states, mathematicians become better engineers and engineers become better mathematicians. This suggests that in order for engineering education to develop the kind of engineer that is required in the 21st century, the mathematical ability of engineering students needs to be enhanced. To accomplish this there must be a dialogic relationship between mathematics and engineering to support advancements in both engineering and mathematics. Drawing from this, I can surmise there is a need to include mathematical tasks that show the relevance of mathematics in engineering contexts. For this to happen mathematicians need to understand the role of mathematics in engineering contexts (Bickley, 1964; Sazhin, 1998; Alpers, 2010). In addition, for engineers to have access to the mathematics that is relevant, that promotes conceptual understanding, research and advancements in engineering, they require access to mathematics that has the potential to facilitate this. This can only be accomplished if there is collaboration between the two disciplines.

It would be beneficial if the disciplines of mathematics and engineering establish a formal committee, not unlike the SEFI MWG, which comprises mathematicians who lecture mathematics to engineering students, engineering lecturers and practicing engineers whose sole purpose is to regulate the mathematics curriculum for engineering students. The task of this committee would be to keep abreast of current trends in engineering practice and engineering education specifically in terms of the mathematics that is required to support engineering education. The committee should engage in research-based practice. That is the implementation of global best practice which has been implemented in institutions that exhibit similar student profiles and socio-economic conditions and which have been researched and found to work (SEFI MWG, 2008). Attendance at conferences on engineering education will provide exposure to current research in engineering education. Researching engineering education within their own practice will enable lecturers to evaluate the effect of the approaches implemented. Longitudinal studies will enable researchers to study the effects of approaches used and facilitate changes in content of the module in the subsequent years. As a team, mathematicians and engineers can elicit best practice within their own environment.

Collaboration between the disciplines of mathematics and engineering could provide the platform for lecturers to identify the mathematics required as well as relevant engineering examples as I believe (and the literature indicates) that it is beneficial to to the teaching and learning environment if lecturers know and understand how the mathematics that they teach is used in engineering practice. Lecturers can thus develop a repertoire of engineering problems that require the use of the specific aspects of mathematics being taught so that the application of mathematics in day-to-day engineering problems can be used to exemplify mathematical concepts. Doing things this way will alleviate the amount of time that lecturers spend trying to plan as they will have assistance in linking the mathematics with authentic, current and relevant engineering contexts. Understanding the context in which the mathematics is used is advantageous to students because it enables them to make connections between mathematics and engineering thereby minimizing the disconnection between the two disciplines. In addition, a mathematics committee for engineering curriculum can facilitate ways to improve teaching and learning in mathematics modules for engineers. Lecturers may be able to identify aspects of mathematics that students have difficulty with in subsequent engineering modules and find ways to address those shortfalls.

The highly debated issue of whether mathematics should be taught in all its abstraction as with mathematicians or in its applications to engineering enhances the support for such a committee. It is through discussion with the various stakeholders that clarity on the engineering curriculum can be reached. For example, one of the concerns that arose is the high volume of work that needs to be completed within the semester. As in other institutions globally, discussion may result in academics agreeing to reduce the content so that more time can be spent teaching less content with the aim of developing conceptual understanding. The opportunity to effectively learn the fundamental mathematical knowledge which the module aims to achieve can be enhanced, for example, by including theorems and proofs.

Bernstein claims that if the curriculum perpetuates dominant ideology then the dominant ideology is hierarchical with strong boundaries, strong classification and framing. Teaching and learning in the ME module is goal-oriented, since the goal seems to be for students to pass the module, rather than outcomes-oriented. This does not align with what the engineering curriculum or the professional body purport. Mathematics for engineers is perceived to be a toolbox that engineers use in engineering practice. In addition, the recontextualisation of mathematics is based on what mathematicians believe to be necessary for engineers. The strong classification of the module makes the content strongly mathematical. Furthermore the privileged view of lecturers in the ME module is that of a toolbox comprising mathematical formulae, rules and procedures. Classification regulates principles of power and the strong classification of the ME module suggests that the ideology of the mathematicians dominates teaching and learning and is thus relayed. Strong classification creates the space for more specialised identities. The views of the lecturers in the ME module dominate and are seen in the recontextualisation at the micro level of the classroom when the theoretical underpinning of mathematical concepts are excluded in lectures.

This is a contradiction as what is currently being propagated as a progressive teaching and learning strategy can actually have the opposite effect (Case, 2011, Muller, 1998). So what pedagogical strategy will inculcate in students the skills, theoretical knowledge and understanding that they require as engineers whilst also enhancing their opportunity for success? Prosser and Trigwell (1999) suggest that a solution may lie in changing the learning context to encourage understanding and the development of problem-solving skills. They suggest that for good teaching to happen university teachers must understand the teaching and learning environment and the nature of the subject (Prosser & Trigwell, 1999).

Given the above, the question that remains is: How do university teachers with little or no educational background understand the teaching and learning environment and the nature of mathematics for engineers?

9.2 Higher Education Lecturers Should Undergo Training in Educational Theories of Teaching and Learning

While it is acknowledged that access to higher education has been increased, widening student participation without providing teachers with adequate knowledge of teaching and learning, particularly within their disciplines, could result in further disadvantages:

> Without an explicit concept of knowledge acquisition, policies that give priority to widening participation and students choices could well be the basis for new, albeit less visible, inequalities. (Young, 2008, p. 10)

It was identified that despite the diverse cohort of students and the changing landscape of engineering and higher education, the approaches to teaching and learning adopted by all three lecturers were algorithmic and assessment-oriented. Teaching and assessments were approached using a ‘one-size-fits-all’ approach and assessments were summative for both formal tests and the final examinations. The lack of feedback and the implications thereof were discussed in Chapter Seven and Chapter Eight thereby highlighting the need for lecturers and 'markers' to provide feedback as an opportunity for students to identify misconceptions, common errors, conceptual difficulties to enhance meta-cognitive development. From the data collected, there was no evidence to suggest that differences amongst students in terms of their learning styles, educational and socio-economic background and language are considered in lecturers' approach to teaching and learning. The data revealed that reasons for the teaching approach adopted ranged from beliefs about mathematics for engineers, beliefs about teaching mathematics to engineering students and contextual factors such as strong framing and challenges associated with students. In addition the strong classification and framing of the module with a high volume of work contributed to the approach to teaching and learning. Lecturers, being disciplinary experts, may not necessarily be aware of the ways in which the quality of teaching and learning can be enhanced in their discipline.

Together with research, teaching is one of the key responsibilities of mathematics academics. Despite this it is widely documented that most mathematics academics in higher education have little if any formal training in pedagogy (Rahilly & Savroyan, 1997) suggesting that the pedagogical knowledge of mathematics lecturers varies considerably. Ball, Lubienski & Mewborne (2001) contend that mathematical teaching in higher education often seems to be regarded as a matter of 'common sense'. How students learn and what pedagogical practices best support this learning should be central to teaching. How do lecturers, who do not undergo training in pedagogy, construct their understanding of how to teach and how students learn? "Knowing mathematics in and for teaching requires one to transcend the tacit understanding that characterises much personal knowledge and requires a unique understanding that intertwines aspects of teaching and learning with content" (Ball *et al*., 2001, p. 24).

Ma's (1999) study of Chinese teachers with an equivalent of grade nine mathematics education followed by at least two years of teacher education and American teachers who were college-trained showed that the American teachers were outperformed by their Chinese counterparts when asked to respond to questions based on mathematics scenarios. This indicates that American teachers were unable to provide adequate explanations for the processes they used in solving the problems proving that higher mathematics qualification does not necessarily lead to better teaching or higher student achievement. Similarly, Astin (1990) ascertained in his study that further studies in mathematics education were a more accurate predictor of teacher effectiveness than was the level of formal mathematics qualification. After a certain point, the correlation between higher qualification and better achievement weakens (Ma, 1999; Hiebert, 1999; Astin, 1990, Monk, 1994; Begle, 1979). In a review of 17 studies, Hiebert (1999) showed that greater qualifications of lecturers contribute to student achievement up to a point and thereafter have no effect on student achievement. Similarly, Monk (1994) found that after five semesters of taking mathematics courses, the relationship between the number of mathematics courses taken by lecturers and student achievement wanes.

Schoenfeld (2001) suggests that the purpose of research in mathematics education is twofold: First its purpose is seen as pure where research is for the purpose of understanding the nature of mathematics teaching, learning and thinking, whilst the second purpose views it as applied where it is expected that this understanding (mentioned above) will be applied to improve mathematics teaching. Both of these, he suggests, have a synergetic relationship as basic knowledge strengthens the basis for application. Furthermore, the application of an approach is dependent on what an academic believes will ‘work’ and its selection should depend on what one wants to achieve considering amongst other constraints, background conditions, understandings and students. Studies have shown that more mathematical knowledge or qualification does not necessarily result in a more effective teacher (Ma, 1999; Hiebert, 1999; Astin, 1990, Monk, 1994; Begle, 1979).

The OECD (2013) suggests that since quality teaching is not necessarily recognised as a priority in higher education, raising awareness about the quality of teaching and encouraging debate may in fact enhance the same. They recommend that lecturers be encouraged to receive grounding in theories of teaching and learning, as this would enable them to recognize and emphasize that understanding is a building block to application. Based on the above discussions, it is my recommendation that staff be encouraged to participate in the university induction programmes which focus on aspects of teaching and learning such as curriculum development, planning of assessments and theories and strategies of teaching and learning mathematics. Further to this, there needs be particular focus on teaching and learning mathematics to future engineers, and using tutorials effectively (for example by creating opportunities for developing problem-solving skills). This would provide the opportunity for academics to develop, not only as researchers who contribute to the research productivity of their discipline and ultimately the institution, but also as teachers. Quality teaching and learning results in better academic experiences (OECD, 2013) leaving no doubt that exposure to teaching and learning development programmes can enhance the teaching and learning environment, particularly in the mathematics class.

The SAHEI has put in place a quality teaching and learning framework. This provides a platform for the induction of new and junior lecturers to enhance their knowledge of teaching and learning with the view of improving the quality of teaching and learning at the SAHEI. The induction courses provide exposure to a variety of teaching and assessment approaches that cater for differences in learning styles and which facilitate the development of tasks that can build towards the ELOs (that is strong alignment between teaching, assessments and module goals). Exposure to different ways of teaching, learning and assessing may influence the framing of the module in terms of maintaining strong framing over selection, sequencing and evaluative criteria, but weak framing over pacing and the teaching styles adopted. However, the potential of the induction courses to enhance teaching and learning will remain exactly that if lecturers do not make use of the opportunity. Lecturers need to be motivated to embrace the opportunity to improve the quality of teaching and learning in higher education.

Furthermore, the ‘publish or perish’ motto has become less dominant with the advent of the promotion policy which places a high value on disciplinary research, research in teaching and learning as well as excellence in teaching. So while previously lecturers may have been concerned that time spent preparing for quality teaching eroded their time for research and therefore prioritized research over teaching, the promotion policy provides the pathway for lecturers to be promoted on the basis of excellence in teaching. Currently the SAHEI initiative to take academics into schools in rural communities provides the opportunity for lecturers to understand the student profile. This can have implications for how teaching and learning are approached because raising awareness of the student profile could lead to lecturers reconceptualising and reprioritizing how they view teaching and learning.

9.3 Tutorials Should be Re-Conceptualised

When asked about the objectives of the tutorial, the HoS responded that the intention was to enhance students' understanding of the mathematical concepts. However he acknowledged that,

> with the large numbers even the tutorials have a diminished use … … so I don't think students fully engage at a tutorial. … It's something that constantly concerns us. (Interview, HoS, 2011)

Interviews with successful students and the student questionnaire generated data which revealed that tutorials were a significant factor in students' success. Although the additional tutorials were found to correlate closely with tests and were thus considered beneficial in students passing the module, several students indicated that the tutorial sessions themselves were beneficial to their learning. Many students mentioned that tutorials provided the opportunity for them to work with peers and to get assistance from tutors and lecturer when necessary. Whilst the tutorials were well-structured in terms of the tasks, times and venues, they lack a structured way of developing problem solving skills, leaving students to develop these skills on their own. Tutorials must be structured such that they expose students to different problem solving strategies and so create the opportunity for the development of problem solving skills.

The SAHEI is tasked with educating a student population that characterizes diversity on many levels. This further entrenches my belief that there can be no 'one-size-fits-all' solution for conducting tutorials. Supplemental Instruction (SI) is a peer driven academic intervention aimed at improving the retention and graduation rates as well as the overall performance of students using organized, collaborative group study. According to Blanc, Debuhr and Martin (1983) SI "is designed to assist students in mastering course concepts and, at the same time, to increase student competency … in reasoning and study skills" (p. 81). Drawing on the literature (Arendale, 2004, 2005; Blanc, Debuhr & Martin, 1983; Doty, 2003), my experience in implementing supplemental instruction (SI) in the School of Mathematics and the School of Engineering and research that has been conducted on the effects of SI at the SAHEI, I can firmly state that SI has proved to be successful in enhancing the student experience and student performance at the SAHEI (Moodley, Bengesai, Paideya

& Singaram, 2012; Bengesai, 2011). Based on this, I recommend that tutorials are modeled on principles of SI and that research be undertaken to assess the effectiveness of the strategies implemented so that tutorials can be customized to suit the needs of the student profile.

In the ME module, the division of students into tutorial groups based on their engineering disciplines provided the opportunity for the specialized content or contextualized problems to be used for the different tutorial groups. For example, collaboration between mathematics and mechanical engineering lecturers could facilitate the construction of mathematical questions specialized for mechanical engineering contexts for use in tutorials. I acknowledge that this may not be an easy task but the literature indicates that such approaches are beneficial to students as they show the application of mathematics in engineering contexts. This is challenging considering the mix of disciplines (more than one) in every lecture, but tutorials provide the opportunity to specialize applications for the different engineering disciplines.

In order for tutorials to be constructive for students and tutors, tutors need to be provided with training if they are to conduct tutorials effectively. For this to be effective training of tutors in terms of punctuality, attendance, tutoring styles, preparation and developing interpersonal skills is recommended. Furthermore, tutorial sessions need to be supervised by the academics lecturing in the module to ensure that they are being conducted effectively. Tutoring should not be seen as a means of providing jobs for postgraduate students but rather as one of the ways in which postgraduate students can be the student experience and ultimately pass rates can be improved.

9.4 Consider Adopting the CHE Proposal for an Extended Curriculum

The literature suggests that under preparedness is a problem that affects the majority of students and not the minority (McKenna, 2010). The CHE proposal promotes an extended curriculum that promises to cater for student diversity and promote retention and throughput rates. The CHE proposal for an extended curriculum (CHE, 2013) is well-timed as it provides a plan that considers the new student profile: large numbers of mathematically underprepared students from diverse backgrounds. It is my contention that given the high student intake and low retention and throughput rates, extending the duration of the degree enhances the chances of success for the majority of students and is thus a plan worth considering. The proposal suggests that a flexible curriculum framework has the potential to address the concerns raised as it provides differential entry points for students depending on the level of their academic preparedness. This means that different groups could receive attention to remedy their inadequacies. Students should be given a baseline assessment upon entry into tertiary education to determine their preparedness for the ME module. Assessment results could be used to determine effective strategies to support underprepared students – this could take the form of a developmental mathematics module or an academic intervention (Supplemental Instruction or extra lessons) to address the gaps in students' knowledge.

9.5 Conclusion of the thesis

This research was a study of teaching and learning mathematics to first year students in an engineering curriculum at a South African higher education institution. The study focused on three key research questions:

- Research Question 1: What is the role of mathematics in the education of future engineers?
- Research Question 2: How is teaching and learning in the ME module approached in lectures, tutorials and assessments?
- Research Question 3: Why is teaching and learning in the ME module approached the way it is, in particular what beliefs do academics have about teaching and learning mathematics to engineering students?

9.5.1 What is the role of mathematics in the education of future engineers? This question was viewed from a national and an international perspective. From the international perspective, the engineering degree and by extension the ME module showed compliance with the Washington Accord and its signatory countries confirming its equivalence with engineering degrees internationally. On a national level, the ME module in theory complies with the statutory body (ECSA) requirements. Data from the literature and interviews with academics from mathematics and engineering showed that mathematics is a critical component underscoring engineering education and practice. The content of the ME module compared favourably with the requirements of ECSA, the mathematical content for engineering in the USA, UK and Australia and the literature on engineering education.

9.5.2 How is teaching and learning in the ME module approached in lectures, tutorials and assessments? To answer this question, the ME module was analysed on the basis of its organization, structure and teaching approaches. The structure of the module was analysed using Bernstein's concepts of recontextualisation, singulars and regions and classification and framing. The quality of assessments was analysed using Bloom's Revised Taxonomy. The evidence showed that recontextualisation of knowledge occurred from the academic discipline of mathematics to the ME module and was influenced by the 'owners' of the pedagogic device which in this case was the school of mathematics (PRF), the textbook (PRF) and ECSA (ORF). Recontextualisation also occurred at the level of the classroom which was evidenced by lecturers omitting certain sections indicated in the content. The tension in the module was evident as the schools of mathematics and engineering were in conflict over control of the pedagogic device. The ME module was established as a region as it was influenced by the academic discipline of mathematics and the field of practice (ECSA). The module was predominantly strongly classified with respect to content on an interdisciplinary, interdiscursive and intradisciplinary level. It also showed a high degree of classification with respect to space and hierarchical relationships. The module was also predominantly strongly framed with respect to selection, sequencing, pacing and evaluative criteria. This meant that students had little control over what was included in the content, the order in which it was taught, the time taken to teach it and the extent to which the assessments criteria were made explicit. The strong classification and framing had implications for teaching and learning and recommendations were made with regard to classification and framing to enhance teaching and learning.

Analysis of the assessments using Bloom's Revised Taxonomy and a comparison of the final and mock examination questions showed that on their own the questions were of a high level of cognitive demand. However, a comparison of the questions in both showed that the congruence between questions was high indicating that the level of cognitive demand was reduced since the questions appeared to have been well-rehearsed. There was strong alignment between what was covered in lectures, the additional tutorial problems, the mock assessments, revision assessments and assessments.

9.5.3 Why is teaching and learning in the ME module approached the way it is, in particular what beliefs do academics have about teaching and learning mathematics to engineering students? Observation of lectures and tutorials and interviews with academic staff and students revealed several influences on how teaching and learning is approached. Lecturers' beliefs about teaching mathematics to engineering students, the nature of mathematics for engineers, their role as lecturers and goals in the ME module were some of the factors that influenced their teaching. In addition the high volume of work, short time frames, lecturers' own experiences of studying mathematics and their perceptions about students prior knowledge, mathematical ability and work ethic were found to be influential in how they approached teaching and learning in the ME module.

This study adds to the knowledge base in engineering education at the SAHEI since research in engineering education at the SAHEI is a new and fast-emerging area of research at the SAHEI. Significantly, research in engineering education is also dominated by academics involved in academic development initiatives in engineering education. It is suggested that research in engineering education become a core focus of the school of engineering and the schools that support modules in the engineering curriculum if retention and graduation rates are to be improved. Research-led practice based on current research in engineering education and policy informing the same should be encouraged. Academic staff should be cognizant of current approaches to teaching and learning, especially in engineering education, the profile of their students and actively monitor student performance and progress. Academic lecturing in the engineering curriculum should know and constantly update their knowledge about the relevance of mathematics to engineering. While its importance was established in this study as central to engineering education and practice, its importance and value must be understood by academics lecturing in engineering modules if they are to teach it in a way that is beneficial to students who are required to know and to apply it in engineering.

9.5.4 Suggestions for further research. Engineering education is a new and emerging area of research at the SAHEI. It is also a field of research albeit new, that is dominated by academics in academic development. Academics in the school of engineering and schools involved with modules included in the engineering curriculum should engage in research-led teaching based on current research in engineering education. Furthermore academics involved in engineering education need to engage in research in teaching and learning, including their own practice, to investigate and identify teaching and learning strategies that enhance teaching and learning. Engineering education is a constantly changing field of research in keeping with a constantly changing landscape. This requires academics involved in engineering education to be knowledgeable about current teaching and learning approaches and best practice. Understanding the relevance of their subjects in engineering education as well as in engineering practice has the potential to enable academics to approach teaching mathematics in the way that it is required to be known thus enhancing the opportunity for students to improve their performance.

My journey through conducting the research and writing up this thesis began with a focus on understanding teaching and learning mathematics to first year students in an engineering context. My role as an ADO in the school of engineering brought me in contact with students, who having been accepted into engineering on the basis of being the best and brightest, were experiencing difficulty in the ME module. These encounters with students who performed well in mathematics at high school yet were experiencing difficulty in first year mathematics in engineering sparked my interest in this area of research. Whilst I acknowledge that both teaching and learning deserve equal importance in the teaching and learning process anecdotal experience showed that much of the blame was placed on student deficit. I therefore sought to understand how teaching was approached and the implications this had for student learning. I hope that I have succeeded in providing an in depth understanding of teaching and learning in the ME module as I intended.

The study which has culminated in this thesis has been a journey through which I have grown both personally and professionally. My personal and professional interest in mathematics education which began almost twenty-five years ago in a high school to the current study in higher education has allowed me the opportunity to engage in research which has culminated in this study that is meaningful to me both personally and professionally. In the process I have ‘discovered’ theorist and theories, which have taken my work in a new direction and given me a broader framework within which to conduct research in mathematics and engineering education. My introduction to the work of Bernstein has been inspiring and while not included in my initial plan as a theoretical framework proved most appropriate. The use of Bloom’s revised taxonomy and academics’ personal theories, which were the theoretical lenses through which certain aspects of the study were analysed allowed me to extend my knowledge of theories that I was already familiar with. Through the years that the research was conducted I had the opportunity to interact with staff and students and acknowledge that I was fortunate to have been involved with people who gave off their time willingly to contribute to this study. While I have reached what to me is a milestone both professionally and personally, I look forward to continuing academic research in mathematics and engineering education.

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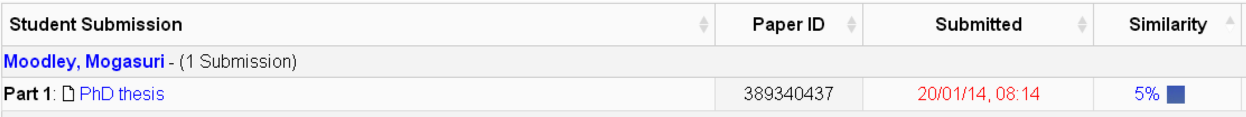
Appendix A



Student Submission	Paper ID	Submitted	Similarity
Moodley, Mogasuri - (1 Submission)			
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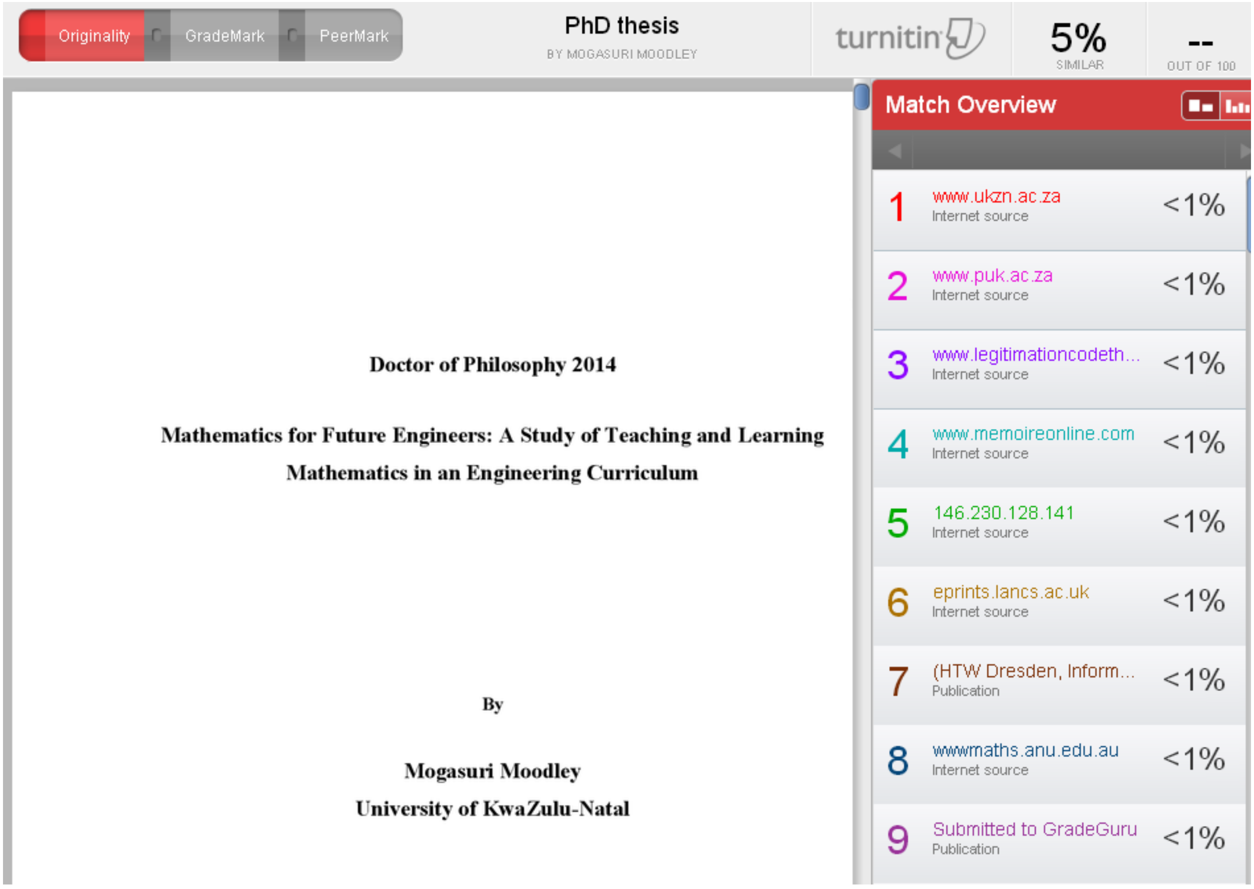

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Appendix B

B: Gatekeeper's permission

UNIVERSITY OF
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INYUVESI
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30 September 2011

Mrs M Moodley (931346383)
School of Mathematics, Science and Technology

Dear Mrs Moodley

PROTOCOL REFERENCE NUMBER: HSS/0935/011D
PROJECT TITLE: Mathematics for future engineers: A study of teaching and learning mathematics in an engineering curriculum

In response to your application dated 20 September 2011, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol has 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 school/department for a period of 5 years.

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

Yours faithfully

....

Professor Steven Collings (Chair)
HUMANITIES & SOCIAL SCIENCES RESEARCH ETHICS COMMITTEE

cc. Mrs S Naicker

1910 - 2010
100 YEARS OF ACADEMIC EXCELLENCE
Founding Campuses: Edgewood · Howard College · Medical School · Pietermaritzburg · Westville

B2: Ethical clearance

UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

6 September 2011

Ms M Moodley
Academic Development Officer
ASAP, Faculty of Engineering
UKZN

Email: moodleym5@ukzn.ac.za

Dear Ms Moodley,

RE: PERMISSION TO CONDUCT RESEARCH

Gatekeeper's permission is hereby granted for you to conduct research at the University of KwaZulu-Natal towards your PhD qualification, provided Ethical clearance has been obtained via the Research Office. It is noted the title of your dissertation is:

1) Mathematics for future engineers: A study of teaching and learning mathematics in an engineering curriculum

Please note that the data collected must be treated with confidentiality and anonymity.

Yours sincerely,

Prof JJ Meyerowitz
Registrar

Office of the Registrar
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1910 - 2010
100 YEARS OF ACADEMIC EXCELLENCE
Founding Campuses: Edgewood Howard College Medical School Pietermaritzburg Westville

Appendix C

C1: ME module lecture timetable

Group A – CV (100), SV (35), CE (70) **Group B** – AG (15), EC (90), EL (95)

Group C – UN (75), CH (110), ME (100)

R1	R2	R3
Mon 2-3 (S9)	Tue 6 (S7)	Mon 7 (S8)
Tue 7 (S9)	Thu 2-3 (S7)	Tue 2-3 (S8)
Thu 6 (S9)	Fri 1 (S7)	Thu 1 (S8)

C2: ME module tutorial timetable

	AM (Periods 2-5)	PM (Periods 8-11)
Monday	EL (S4)	CH (S7)
Tuesday		UN&AG (S5&S6)
Wednesday	CV (S4)	ME (S7)
Thursday		SV&CE (S8)
Friday	EC (S8)	

C3: Tutor allocation for the tutorial sessions in the ME module.

Day	Periods	Discipline	N	Lecturer	Tutor
Monday	4, 5	Electrical engineering	95	DR A & Tutor A	Tutors A, B, C
Monday	8, 9	Chemical	110	Dr C & Tutor H	Tutors D, E, F
Tuesday	8, 9	Agricultural, UNITE	90	Dr C & Tutor G	Tutors F, G, H
Wednesday	4, 5	Surveying	35	Dr B & Tutor I	Tutors J, I, K
Wednesday	8, 9	Mechanical	100	Dr A & Tutor L	Tutors M, N, L, O
Thursday	8, 9	Civil	100	Tutor X	Tutors P, Q, R, S
Friday	4, 5	Electronic	95	Dr B & Tutor T	Tutor T, U, V, W

Appendix D

Schedule of lecture observations

Lecturer	February	March	April	May
Dr A	**6, 14, 15, 16, 21, 23**	**5, 29**	**5 (2), 7, 12, 24,**	
Dr B	**9, 23, 24**	**8, 9, 23 (2)**	**16**	**17**
Dr C	**7, 21**	**26 (2), 30**	**6**	**7, 14 (2)**

Appendix E

E1: Summary of classification and framing of pedagogic discourse

	Dr A	Lectures	Tutorials
Framing	Selection of content/ problems	F++	F++
	Sequencing of content over semester	F++	F++
	Sequencing of content in lecture	F+	NA (no content)
	Sequencing of problems in lecture/ tutorial	F++	F--
	Pacing of content over semester	F++	F++
	Pacing of content in lecture/ tutorial	F++	F+
	Evaluative criteria within lectures/ tutorials	F++	F++
	Evaluative Criteria – students responses	F+	F-
	Spaces (Inside/ outside)	C++	C++
Classification	Within	C+	C-
	Inter-disciplinary	C-	C++
	Intra-disciplinary	C+	C++
	Inter-discursive	C+	C++

	Dr B	Lectures	Tutorials
Framing	Selection of content/ problems	F++	F++
	Sequencing of content over semester	F++	F++
	Sequencing of content in lecture	F+	NA (no content)
	Sequencing of problems in lecture/ tutorial	F++	F--
	Pacing of content over semester	F++	F++
	Pacing of content in lecture/ tutorial	F++	F--
	Evaluative criteria within lectures/ tutorials	F++	F++
	Evaluative Criteria – students responses/ questions	F+	F-
Classification	Spaces (Inside/ outside)	C++	C-
	Within	C++	C-
	Inter-disciplinary	C++	C++
	Intra-disciplinary	C++	C++
	Inter-discursive	C++	C++

	Dr C	Lectures	Tutorials
Framing	Selection of content/ problems	F++	F++
	Sequencing of content over semester	F++	F++

	Sequencing of content in lecture	F+	NA (no content)
	Sequencing of problems in lecture/ tutorial	F++	F--
	Pacing of content over semester	F++	F++
	Pacing of content in lecture/ tutorial	F++	F--
	Evaluative criteria within lectures/ tutorials	F++	F-
	Evaluative Criteria – students responses/ questions	F++	F-
Classification	Spaces (Inside/ outside)	C++	C+
	Within	C++	C-
	Inter-disciplinary	C++	C++
	Intra-disciplinary	C++	C++
	Inter-discursive	C++	C+

E2: Observation schedule for lectures

Lecturer: Dr B______ Observation lesson: 01________

Makes an effort to build students understanding through:

1 Never (0 times)	2 Sometimes (2 times in the lesson)	3 Many (four times)	4 Consistently (more than 4 times)	

1. Encourages students to question					
2. Encourages students to think					
3. Encourages discussion/ interaction between students					
4. Encourages discussion between student and lecturer					
5. Considers students suggestions/ solutions					
6. Class activities encourage exposing, justifying and demonstrating answers					
7. Creates/ uses mathematical activities to reflect on mathematical ideas					
8. Follows through on students ideas					
9. Asks questions of students to encourage thinking, PS skills					
10. Encourages students to guess, make conjectures and reason out solution to problems					
11. Encourages skill development and computation					
12. Demonstrates procedures that students must use					
13. Encourages students to practice procedures taught					
14. Emphasise formal geometric proofs					
15. Accentuates a single correct answer					
16. Teaching rules without explanation of how and why it works					
17. Preparation of students for subsequent mathematics/ engineering modules					
18. Emphasise taking notes or using notes put up online					
19. Memorisation of rules/ methods/ procedures					
20. Emphasises following step-by-step procedures step-by-step procedures will lead to the correct answer					

Observation schedule: Dr A

Question ➔ Lesson ⇩	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1	1
2	2	2	1	1	1	1	1	1	1	1
3	1	1	1	1	1	2	1	1	1	1
4	3	1	1	2	2	1	1	1	1	1

Observation Schedule: Dr B

Question ➔ Lesson ⇩	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	√	1	1
3	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1

Observation Schedule: Dr C

Question ➔ Lesson ⇩	1	2	3	4	5	6	7	8	9	10
1	1	3	1	3	2	1	1	1	3	1
2	1	1	1	2	2	2	1	1	1	1
3	1	1	1	2	2	1	1	1	1	1
4	2	1	1	2	1	2	2	1	2	1

Appendix F

Comparison of mock and final examination papers and Comparison of questions in revision test, mock test and test one.

F1: Comparison of mock and final examination papers (ME module, semester 1, 2012)

Question 8: Mock Examination Paper

(b) Sketch the graph of y = sinhx, x € [0; ln 4}

(i) Divide the interval into n subintervals and write down an expression for the sum of the areas of rectangles under the curve in terms of n by evaluating the height of each rectangle at the right hand end point of each subinterval, $tag = C_j$. How can you find the actual area using your result? [3]

Question 8: Final Examination Paper

(b) Sketch the graph of y = coshx, x € [0; ln 2}

(i) Divide the interval into n subintervals and write down an expression for the sum of the areas of rectangles under the curve in terms of n by evaluating the height of each rectangle at the right hand end point of each subinterval, $tag = C_j$.

How can you find the actual area using your result? [3]

F2: Comparison of revision test, mock test and test one (ME module, semester 1, 2012)

2.Sketch f(x): Sin $f(x) = \begin{cases} 2/x; & x \geq 2 \\ -\sqrt{2} - x; & x < 2 \end{cases}$ Calculate: $\lim_{x \to -1} f(x)/x$ $\lim_{x \to 2} f(x)$	2.Sketch the piecewise graph: $f(x) = \begin{cases} 1/(x-2); & x \geq 3 \\ 4 - \lvert x \rvert; & -3 \leq x \leq 3 \end{cases}$ For the above function find: $\lim_{x \to -1} f(x)$ Is y = f(x) continuous at x = 3?	2.Sketch the piecewise graph: $f(x) = \begin{cases} 1/(x-3) + 1; & x \geq 4 \\ \lvert x + 1 \rvert; & x < 4 \end{cases}$ For the function above find: $\lim_{x \to -1} f(x)/(x+1)$ Explain your answer
a) $\lim_{x \to 2} (x2 + x - 6)/(x - 2)$ (b) $\lim_{x \to 3^-} (\lvert x + 3 \rvert/(x + 3)$ (c) $\lim_{x \to 7}(\sqrt{}(12x^3 - 5x + 2)/(1 + 4x + 3x^3)$ (d) $\lim_{x \to \infty} (3x^2 - x + 4)/(2x^2 - 15x - 8)$ (e)Use the squeeze theorem to evaluate: $\lim_{x \to \infty} \sin x/x$: $-1/x \leq \sin x/x \leq 1/x$ [Hint: use the squeeze theorem]	a) $\lim_{h \to 0} h/(\sqrt{x} + h - \sqrt{x}$ (b) $\lim_{x \to 3^-} (\lvert x - 3 \rvert/(x - 3)$ (c)$\lim_{x \to 1} (x - 1)/(x^2 - 2x + 1)$ (d) $\lim_{x \to \infty} (x^4 - 3x^2 + 2)/(x^3 - 2x^4 + 1)$ (e)$\lim_{x \to 0} g(x)/f(x)$ given that: $-x^4 + \sqrt{2}x^2 \leq g(x) \leq \sqrt{2}x^2 + x^4$ [Hint: use the squeeze theorem]	Evaluate the following limits: (a) $\lim_{h \to 0} h/(\sqrt{x} + 2h - \sqrt{x}$ (b) $\lim_{x \to 2} (x + 2)/(x^2 + 4x + 4)$ (c) $\lim_{x \to \infty} (x^4 - 3x^2 + 2/(x^3 - 2x^4 + 1)$ (d) $\lim_{x \to \infty} \sqrt{}(25x^8 - 3x^6 + 6 - 5x^4)/(x^2 - 2x + 1)$ (e)$\lim_{x \to \infty} g(x)/f(x)$ given that: $-x^2 + \sqrt{3}x^4 \leq g(x) \leq \sqrt{3}x^4 + x^2$ [Hint: use the squeeze theorem]
	Prove using the definition of the limit that $\lim_{x \to -2} (4 - 3x) = 10$	Use the definition of the limit to prove that $\text{Lim}_{x \to -4} (2x + 1) = -7$

(Source: learning@sahei.ac.za, 2012)

Appendix G

G1: Interview questions for lecturers

Q1. How would you define mathematics

Q2. What is the goal in the mathematics class?

Q3. How is mathematics knowledge justified?

Q4. What does it mean to do mathematics

Q5. Are all students capable of doing mathematics?

Q6. How should students go about learning mathematics in this module

Q7. What are some of the reasons students are successful in this module?

Q8. What are reasons for their failure

Q9. How would you describe the mathematics students in your class?

Q10. What is your perception of how students learn mathematics?

Q11. How well do you think students learn the mathematics that they require for engineering

Q12 .Where does calculus fit into engineering?

Q13. What are some of the challenges in the ME module?

Q14. What would you suggest to improve the pass rates in engineering?

Q15. Do you observe each other's lectures?

Q16. How are assessments drawn up?

Q17. Are lecturers privy to the tests beforehand?

Q18. Who selects tutors and are they trained? Do they prepare beforehand? Are they supervised?

G2: Interview questions for students

1. How did you go about or make use of: "talk a bit about the preparation you did before each lecture."
   (probe to illicit how they prepared for each, how they made use of the sessions, and whether it was beneficial to their success)
   - lectures?
     ____
     ____
   - Tutorials
   - ____
     ____
   - Asessments
   - ____
     ____
     ____
   - Website
   - ____
     ____
2. What can you pick out as they key aspects that were instrumental in your success in this module?
   (probe for reasons eg. Following lecturer/ tutor advice – which piece of advice, working with peers, …)
   ____
   ____
   ____
3. What advice would you give to a student doing this module for the first time?
   (probe to get input on lectures, tutorials and assessments, consultation, use of website)
   ____
   ____
   ____
   ____
4. Did you see alignment between lectures, tutorials and assessments including examinations? _____. Explain.
   (Probe to determine whether there seemed to be a good fit between the three components – if they did all properly was there a good indication of what the module was about and how it was to be tested?)
   ____
   ____
5. What components of this module do you think need to be improved? (Probe to determine specific aspects of the ccomponents that were not helpful in their learning eg. Longer lecture times, smaller classes, tutorials, feedback on assessments, website, textbook etc.)
   ____
   ____

To summarise, do you think longer lectures would help? Smaller classes, … ? (this way I will be are sure of an opinion on each point as well as their initial free response).

Appendix H

Comparison between pure mathematics and engineering mathematics curricula (adapted from the SAHEI of AES Handbook, 2012)

	Introduction to calculus	Mathematics for Engineers (ME module)
Prerequisite requirements	Mathematics at D (HG) or A (SG) or NSC level 5(60 %)	Mathematics at C (HG) or A (SG) or NSC level 6 (70 %)
Aim	To introduce and develop the differential calculus as well as the fundamental of proof techniques and rudimentary logic	To introduce basic mathematical concepts of differential and integral calculus
Content	Fundamental concepts – elementary logic, proof techniques. Differential calculus – Functions, graphs and inverse functions, limits and continuity, the derivative, techniques of differentiation, application of derivatives, anti-derivatives.	Elements of logic and set theory. Functions and their graphs, limits and continuity. Differentiation. Application of derivatives to optimization and curve sketching, linear and quadratic approximation, Newton's method. Indeterminate forms. Inverse trigonometric and other transcendental functions. Indefinite integrals, basic techniques of integration. Definite integrals. Approximate integration. Applications in geometry, physics and engineering.
Assessment	Class tests and/ or assignments (33%) 3 hour examination (67%)	Class tests and/ or assignments (20%) 3 hour examination (80%)
DP requirement	35% class mark , 80 % attendance at lectures and tutorials	35% class mark , 80 % attendance at lectures and tutorials
Other		For engineering students only.
	49 hours of lectures 39 hours of tutorials 51 hours of self-study 15 hours of revision 6 hours of assessment (3 x 1 hour tests and a 3 hour examination). 13 week module 16 credits	39 hours of lectures 39 hours of tutorials 56 hours of self-study 20 hours of revision 6 hours of assessment (3 x 1 hour tests and a 3 hour examination). 13 week module 16 credits