PATTERNS WITHIN PROBLEM-BASED LEARNING: HOW A PRIOR MATHEMATICS FAILURE AFFECTS ENGINEERING DIPLOMA STUDENTS

By

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other institution, and, to the best of my knowledge, the thesis contains no material previously published or written by another person, except where due reference is made in the text of thesis.

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Preman Rajalingam

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This research project was granted approval by the Standing Committee on Ethics in Research Involving Humans (SCERH) of Monash University, on 16 May 2008 (Project Number: CF08/0958 - 2008000477)

Dedication

Dedicated to all my fellow procrastinators, you know who you are.

Start writing now, dammit!

Acknowledgements

Many people have provided encouragement and assistance since the beginning of my candidature back in April 2008. It is hard to imagine doing this without their support. I would like to take this opportunity to thank them and acknowledge their contributions to this thesis.

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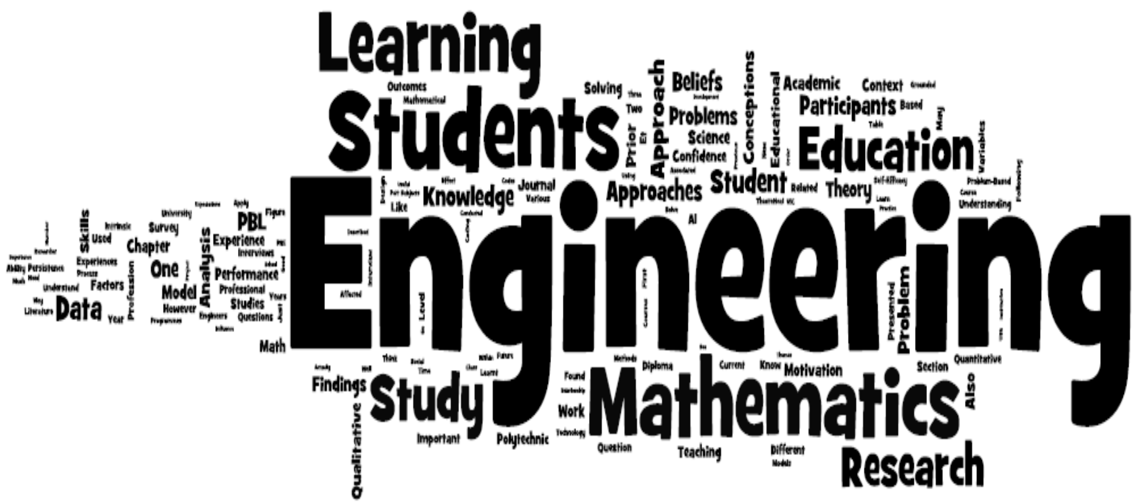
Abstract

Historically, the progress of engineering has been so closely associated with the progress of mathematics that some have found it hard to separate the two disciplines. Within engineering education, it is often taken for granted that a good engineering student is also good at mathematics. Thus, prior performance in mathematics is usually an important consideration for admission into most engineering programmes.

This doctoral study was conducted in a unique context at a polytechnic in Singapore, where a small number of students who failed mathematics were admitted into engineering programmes, and Problem-Based Learning (PBL) was the dedicated pedagogical approach. The aims of this study were to identify important issues in engineering education that were associated with prior mathematic performance, and to understand the experiences of those engineering students who had failed mathematics. The study adopted a mixed method research design; quantitative data were collected from 1217 students using an institution-wide survey, and nine students who failed mathematics were interviewed to collect qualitative data.

The quantitative findings showed that the effect of prior mathematics performance on performance in engineering courses was small, compared to its effect on psychological characteristics such as academic confidence and intrinsic motivation. In addition, a prior failure in mathematics generally led students to form certain qualitatively different "Conceptions of Mathematics", which adversely affected their "Conceptions of Engineering". These conceptions were linked to their academic confidence and intrinsic motivation, which in turn influenced their intention to persist in engineering. Based on

these findings and relevant educational theories, a model was proposed to explain why the students' prior experiences in mathematics influenced their learning in engineering as well as their motivation for an engineering career. This study lends support to the notion that the psychological outcomes of engineering education should be considered as important as its cognitive outcomes, in making pedagogical and policy decisions.



Chapter 1 Introduction

The PhD study reported in the following pages is a systematic inquiry in the area of 'Engineering Education'. Specifically, it is an investigation of how prior experiences in mathematics could affect the learning process and outcomes of a student enrolled in a Problem-Based Learning (PBL) engineering diploma course. The purpose of this opening chapter is to introduce the background, educational context and goals of this study. The sections that follow are designed to help the reader better understand the context, the research problem and the research questions that guide the rest of the study.

1.1 ***Background***

Scientific knowledge and, by association, engineering knowledge is supposed to double every 10 years (Clough, 2004; Michael, 1999). Many engineering academics and some leaders of industry have argued that only a small number of students can absorb all the essential technical and non-technical knowledge as well as the necessary practical experience in four years of higher education (Augustine, 1994). This problem has been made worse by a general decline over the last two decades, in student motivation and mathematics ability (Bowen, Prior, Lloyd, & Newman-Ford, 2008; Jamieson, 2007; Johnson & Jones, 2006). There have been suggestions (Messerle, 1995) that engineering students must be given more time to reflect on their work and to take part in cultural, social and sporting events, for the sake of their all-round development. There have also been appeals by some engineering educators (Bryant, 2006; Burns & Chisholm, 2005; Maskell,

1999) for the teaching of engineering to adapt to changing technology and student interests, or risk becoming irrelevant.

Conventionally engineering has been taught somewhat deductively, via teacher-centred pedagogies, as embodied by the traditional lecture based model of teaching and learning. In this approach, as defined by Prince and Felder (2006), the instructor presents a topic by lecturing on universal engineering principles, then uses these principles to derive mathematical models and shows illustrative applications of these models. Students, on their part, practice similar derivations and applications in homework and prove their ability to do the same sorts of things in examinations. Some criticisms of an overreliance on this type of education in engineering are, that it: is an ineffective instrument of learning (Hills & Tedford, 2003); fails to replace prior misunderstandings with new knowledge (King, 1994; Mestre, 1994); does not allow students to gain problem solving skills (Jonassen, Strobel, & Lee, 2006); and, leads to memorisation of factual information without provoking understanding of complex concepts (Loverude, Kautz, & Heron, 2002).

Felder and Brent (2004) assert that an inductive approach to teaching and learning is a better alternative to more deductive teaching and learning methods for engineering. However, they recognise that 'inductive teaching and learning' is an umbrella term that incorporates an array of instructional approaches. The common variants of inductive teaching and learning approaches are inquiry learning (Bateman, 1990; Lee, 2004), Problem-Based Learning (PBL) (Barrows, 1996; Norman & Schmidt, 1992; Woods, 1994), project based learning (Dym, Agogino, Eris, Frey, & Leifer, 2005), case based teaching

(Kardos & Smith, 1979) and discovery learning (Spencer & Jordan, 1996). While these inductive approaches vary, one similarity seems to be that each of these approaches intentionally helps students learn how to solve problems (Prince & Felder, 2006).

In accord with the educational literature, there has also been an on-going shift in educational approaches in several engineering programmes around the world (Jonassen, et al., 2006; Newman, 2003). Many of these engineering institutions have moved away from traditional classroom based instruction, that has been characteristic of engineering education for at least fifty years (Holt & Solomon, 1996), towards teaching a significant amount the curriculum via inductive student-centred approaches.

The most common inductive teaching and learning approaches employed in these institutions were found to be PBL and project based learning. In respect to research on the efficacy of PBL, individual studies have found a positive effect on a number of areas. These include skills development (Albanese & Mitchell, 1993; Vernon & Blake, 1993), understanding the interconnections between various concepts (Gijbels, Dochy, Bossche, & Segers, 2005), deep conceptual understanding (Dods, 1997), ability to apply appropriate metacognitive and reasoning strategies (Chung & Chow, 2004), class attendance (Lieux, 1996) and development of key process skills (Woods et al., 1997). PBL has also been shown to promote self-directed learning (Blumberg, 2000) and the adoption of a meaning centred approach to learning as contrasted with a memorisation centred approach to learning (Coles, 1985; Felder, Felder, & Brent, 2005; Norman & Schmidt, 1992).

It should be noted that there are still a number of unresolved disputes regarding the efficacy of PBL compared to more traditional methods (Hung, Bailey, & Jonassen, 2003). These are depth as opposed to breath of curriculum (de Graaff & Kolmos, 2003); higher-order thinking set against factual knowledge acquisition (Perrenet, Bouhuijs, & Smits, 2000); long-term effects versus instant learning outcomes; traditional roles of educators compared with the role of PBL facilitators; and, initial student discomfort as opposed to the possible long term positive attitudes (Felder & Brent, 1996).

PBL was originally developed for medical education, and much of the research into PBL comes from this context. However, learning engineering requires different skillsets and the background of most engineering students is unlike medical students. Some authors have questioned the suitability of applying a PBL approach in engineering (Mills & Treagust, 2003). However, the use of PBL in engineering education is not devoid of research. PBL is right now being tried and tested in engineering classrooms and there is a growing body of research literature (Christensen, 2008; Gibbings, Brodie, & Street, 2006; Hsieh & Knight, 2008; Jonassen, et al., 2006; Kestell & Clifton, 2004; Krishnan, Vale, & Gabb, 2006; Moreno, Reisslein, & Ozogul, 2009; Roberto, Ribeiro, da Graca, & Mizukami, 2005). More research is good for engineering education. Though, some authors claim that even though the field of engineering education research has seen substantial growth in the last five years, it needs to have stronger theoretical foundations and empirical rigour to contribute to the science of learning (Johri & Olds, 2011). This type of research, particularly on the ways in which engineering students approach and direct their learning in a PBL setting, is limited. To contribute to the science of learning in this area is one intention of this study.

1.2 ***Educational Context***

The five polytechnics in Singapore cater to the largest segment of students in the tertiary education sector (in Singapore). Most of the students who enrol in the polytechnics do so after completing the General Certificate of Education (GCE) ‘O’ level exam at the end of their secondary education. In any particular year, about 40% of all the students who take the GCE ‘O’ level exam enrol in one of the polytechnics (Ministry of Education, 1998, 2007). The polytechnics offer a wide range of courses in various fields, including (but not limited to) engineering, business studies, nursing, tourism and hospitality management, mass communications, digital media and biotechnology. Polytechnics were intended to provide the option for an industry-oriented education as an alternative to enrolling in a university for tertiary studies. Graduates from the polytechnics obtain a diploma in their field of study after three years of education. Most enter the workforce after graduation, however a cohort study by the Ministry of Education (2007) found that 40% of polytechnic graduates obtain a degree from a university within five years of graduation. This Ministry of Education study also found that of most of the graduates who obtained a degree, undertook their degree courses over a period of 13 and 36 months, with the majority of them pursuing their further studies by going abroad or taking distance learning programmes. Almost half of the engineering diploma holders who pursued degree courses did so in areas other than engineering.

All the data collection for the current study was carried out in one of the five polytechnics in Singapore, in an authentic though somewhat unique PBL setting. The polytechnic that was the site for this study was the newest in the country, enrolling its first cohort of students in 2003. Even though the objective of all polytechnics is to achieve the Ministry of Education's mission (2011) of developing "practice-oriented and knowledgeable middle-level professionals" (in "Polytechnics", para. 1), the polytechnic where this study was conducted stands out in regards to its educational approach. In this polytechnic, the dedicated instructional method for all its programmes is Problem-Based Learning (PBL). Unique to this polytechnic's approach to PBL is that students work on one problem during the course of one day. This means that the problem analysis, self-directed learning and reporting phases of PBL all occur and are concluded within the course of one day (Alwis & O'Grady, 2002).

Currently there are a small number of students enrolled in all of the five polytechnics in Singapore, who did not attain the minimum passing grade in at least one of the 'core subjects' in the GCE 'O' level exam at the time of admission. These students are allowed to enrol in diploma programmes on a case-by-case basis and they are required to retake and obtain a passing grade in that 'core subject', prior to graduating from the polytechnic. 'Core subjects' are 'O' level subjects which students are usually required to pass in order to be admitted into the polytechnic course for which they have applied. For example, for engineering courses the 'core subjects' are English language, a mathematics subject and a science subject. Being the newest polytechnic in the country with the least established "brand name", this polytechnic admitted a greater share of students who performed poorly in the GCE 'O' level compared to the other polytechnics. In-between the years 2009 to 2010, there were approximately 400 students who had failed 'O' level Mathematics prior to admission and were enrolled in one of the three years of an engineering program at this polytechnic. How these students deal with a three-year engineering diploma programme is an area of concern for students and staff. Rightfully so, as a good deal of both anecdotal evidence and research has affirmed the importance of a good understanding in the initial mathematics course and its correlation with success in engineering programmes (Budny, Bjedov, & LeBold, 1997; Cartier, Plante, & Tardif, 2001; LeBold, Lowenkamp, & Ward, 1989; Shaw & Shaw, 1997).

While there exists a significant body of research and theories about learning in a PBL setting (Budny, et al., 1997; Cartier, et al., 2001; LeBold, et al., 1989; Shaw & Shaw, 1997), no theory has been encountered that informs how failing mathematics affects how engineering is learnt in such a context. In order to investigate this issue it is necessary to understand the learning context. The following sections describe in detail the pedagogical structure, course design, teaching techniques and assessments that makeup this particular PBL context.

1.2.1 *Structure of the Learning Day*

As mentioned earlier, the PBL cycle in this polytechnic is unique, with an emphasis on a daily routine where students work on a single problem throughout the day. Learning takes place in a class setting consisting of no more than 25 students and a single tutor. The students are grouped into teams of five. The daily routine consists of three meetings with tutor interaction and two periods of self-directed study or teamwork without tutor involvement. This problem-based approach, though exceptional because it has a shortened learning cycle, has all the attributes of other PBL structures. These attributes are that: (1) all learning starts with a problem; (2) students collaborate in small groups; (3) learning is self-directed, i.e., students are encouraged to formulate their own learning goals and find their own resources; and, (4) no direct instruction is provided, i.e., tutors facilitate learning but do not teach (Colliver, 2000; Dolmans, de Grave, Wolfhagen, & van der Vleuten, 2005; Morrison, 2004; Norman & Schmidt, 2000).

What follows is a brief description of the five phases that make up the structure of the learning day:

Phase 1 First meeting or problem analysis phase (approximately 1 hour):

Here the tutor presents the problem for the day. Students work in teams of five, and discuss the scope of the problem in order to identify their own prior knowledge, knowledge gaps and learning issues. They may also strategize on the problem solving approach to adopt as a team.

Phase 2 First self-directed learning period (approximately 1 hour):

Students do individual research and work with their teams on worksheets provided. Most of the individual research is done by checking online resources from the internet, or occasionally by referring to textbooks. Time is also spent peer teaching, which students are encouraged to do if their classmates encounter issues they do not understand while doing individual research.

Phase 3 Second meeting or knowledge scaffolding phase (approximately 1.5 hours):

Students meet with the tutor to share how they have approached the problem, as well as any learning obstacles they have encountered. The tutor usually spends about 20 minutes with each team during this time, while the other teams continue with their research and/or discussion. The tutor may introduce additional material to the students, ask questions that drive the student teams to inquire more or, suggest additional strategies for them to adopt.

Phase 4 Second self-directed learning period (approximately 2 hours):

A second extended learning period where teams consolidate their research and formulate a response to the problem. In most cases, the teams' responses to the problem are in the form of PowerPoint slide presentations. However, depending on the subject being taught, teams may choose to share their response in a myriad of other ways. In some engineering modules, students may demonstrate and explain the workings of a circuit, simulation or prototype that they have created.

Phase 5 Third meeting or reporting phase (approximately 2 hours):

All the teams in the class present their consolidated findings and response to the problem. In their presentation, each team has to defend their response to the problem and elaborate on their response based on questions raised by peers and the tutor. The tutor also clarifies key ideas at the end of all the student presentations, if they were not adequately addressed by the class discussion.

Students encounter a different problem daily and experience this learning cycle five days a week throughout most of the three-year curricula at the polytechnic. There are two semesters in each academic year with each semester lasting 16 weeks. The next section describes how the three years of an engineering diploma programme are structured.

1.2.2 *Design of the Engineering Programme*

In the one problem a day approach described in the previous section, students only need to concentrate on one topic for the duration of one day, allowing them to work on smaller and more manageable units of learning. Additional guidance is provided by splitting the day up into three meetings during which the tutor can closely monitor students' progress and if necessary intervene to guide them towards meeting their learning objectives. The rationale behind this one problem a day approach is that it provides relatively young students, who may not have been adequately prepared for self-direction prior to entering the polytechnic, more structure and guidance in their learning.

A student is typically enrolled in four to five courses each semester. They study for a different course on different days of the week and by implication, solve a problem that is associated with a different subject daily. Most problems are standalone and increase in complexity as students' progress through their course and years of study. However, problems are purposefully designed to encourage students to apply the knowledge they have gained from solving previous problems. All students have a laptop computer with which they access the school's intranet. The problems, learning materials, and assessments are accessible via this e-platform.

First-year engineering courses are broad based subjects to equip students with the basic theoretical knowledge to solve problems that are more complex later on. These include courses in mathematics, physics and critical thinking. In the second-year, students have to complete courses in subjects specific to their diploma of study. For example, a second-year student studying for a Diploma in Biomedical Electronics will have to complete courses in digital electronics, microcontroller systems and printed circuit board design. In the final-year, students complete specialised subjects that relate closely to the industry that they can expect to work in after graduation. A third-year biomedical electronics student would be enrolled in courses such as biomedical signal processing and biomedical instrumentation. In the third-year, students also have to complete a capstone project to demonstrate that they can integrate and apply the knowledge they have gained over three years. Throughout the three-year curriculum, students are also allowed to enrol in and complete a number of elective courses outside the domain of engineering.

These classroom-based courses are not the only ones that students are required to complete. By the end of the second-year, students are further exposed to the engineering profession by having to complete a course where they have to engage with the engineering industry or engineering professionals. In this course, they profile a topic related to an engineering related business, industry sector or strategic engineering issue, problem or case study. Students are required to do self-directed research, critically analyse and creatively reflect on the factors that drive the area that they have chosen to profile. Finally, in the third-year, students have to work in teams, to complete a capstone project to demonstrate that they can synthesise and apply the knowledge they have gained over three years.

1.2.3 *Tutors and Teaching*

Even though PBL is a student-centred approach to learning, the role of the tutor in PBL is still extremely important (Albanese, 2004; Hmelo-Silver, 2004). What the tutor does in the classroom, in combination with the course design, assessment method, quality of the problem, learning resources and the students' prior knowledge, can determine the quality of the students' learning experiences. Numerous studies on PBL have shown the effect of the tutor on students' motivation to learn (Chung & Chow, 2004; Rotgans & Schmidt, 2010), their group functioning and dynamics (Dolmans, et al., 2005), and their academic achievement (de Grave, Dolmans, & Van Der Vleuten, 1999; Schmidt & Moust, 1995). It is also known that differences in individual tutors' subject matter knowledge and their ability to facilitate the learning process are important factors that can affect student learning (Das, Mpofu, Hasan, & Stewart, 2002; Groves, Régo, & O'Rourke, 2005).

In the polytechnic where this study was conducted, tutors are primarily hired because of their knowledge of the subject matter and relevant experience in industry. However, they are required to employ teaching techniques that are congruent with the PBL approach. This means that asking questions rather than giving answers plays a primary role in the way they interact with students. Questions that promote open discussions (Dillon, 1988) are vital to learning in a PBL classroom that encourages divergent thinking, which is achieved via group dialogue and critical reasoning (Davis, 1999). In a study of an expert PBL tutor, Hmelo-Silver (2002) identified that the tutor accomplished his or her role largely through metacognitive questioning, and questioning that focussed students' attention and elicited causal explanations. The study also found that the expert tutor used a flexible set of strategies, to get students to construct causal models and explain their reasoning to an extent where they realised that the limitations of their knowledge necessitated further learning.

As the explanation above suggests, the tutor's role involves much more than just overseeing the PBL process, he or she is an integral part of the educational context. Loughran (2009) has argued that this role should be treated as being based in a distinct discipline (the discipline of teaching) and that tutors themselves should be educated in real and meaningful ways and see their pedagogic knowledge and skills as distinct elements of the discipline. To prepare tutors for this type of teaching they are required to attend a five-day PBL orientation programme before entering a class. This programme is intended to familiarise them with the PBL structure used at the polytechnic and to introduce the rationale behind the polytechnic's approach to pedagogy. In addition, tutors are expected to fulfil a further 90 hours of PBL training in their first 18 months of service. The purpose of these programmes is to ensure some level of consistency and quality in the teaching techniques adopted by tutors. This suggests then that the polytechnic views the teaching approach as something more than a generic and common sense approach to pedagogy more in line with Loughran's (2009) view of practice than that perhaps more commonly noted in the tertiary sector.

A recent study by Williams, Alwis, and Rotgans (2011) within this educational context, found that, in general, tutors were consistent in their teaching behaviours when they taught different classes and courses. The study also indicated that tutors' dissimilar levels of expertise and ability to facilitate learning, were variable factors in influencing the classroom experience. The tutors' teaching ability matters, and the effect of the tutor has to be taken into account when comparing similar courses taught by different tutors. However, this study is interested in the generalisable effects on learning across the entire engineering diploma programme. Therefore, the influence of individual tutors is mitigated by the fact that that a student may encounter around 20 different tutors in his or her three-years of study.

1.2.4 *Assessment Methods*

Assessment of students is a significant influence on student learning (Bloom, Madaus, & Hastings, 1971; Rust, 2002; Scouller, 1998). Some authors argue that assessment is the most significant influence, and that inappropriate assessment can push students towards learning less effectively (Ramsden, 1988). Assessment of students' knowledge and learning, in the educational context described here, takes place at two levels. Firstly, students have to take four formal knowledge acquisition tests per module, at timed intervals during a semester. Students are tested on their ability to understand and apply what they have learnt. Each knowledge test consists of structured questions that have to be completed within 30-minutes and is conducted in a supervised manner, akin to that of end-of-course examinations. Secondly, each student is given a grade daily based on the facilitator's judgment of the quality of learning in the classroom within the scope of a given PBL problem. The formal knowledge test described earlier is comparable to the typical written assessment, commonly employed in universities and other polytechnics. The daily grade awarded by the facilitator is a unique feature of the educational context, and thus needs to be explained further.

The daily grade of a student is made up of four elements: (1) a reflection journal to be written by each student; (2) a self-assessment exercise; (3) a peer assessment exercise; and, (4) a professional judgment by the tutor as to how well a student has performed during a day. The reflection journal consists of a short essay created by the student, who documents his or her personal reflections to learning and development. The self-assessment consists of eight items inquiring into the quality of students' performance within their teams. The peer assessment consists of four items inquiring into the cooperativeness and quality of contributions of peers within the team. Students are asked to respond to these items on a five point Likert scale with the descriptive anchors "strongly disagree", "disagree", "neutral", "agree" and "strongly agree". The tutor's professional judgment is an opinion formed after deliberating on and considering students' learning processes, and their responses on the reflection journal, self and peer assessment exercises. Studies conducted within this educational context (Lew, Alwis, & Schmidt, 2010; Lew & Schmidt, 2011) show that student reflections and, self and peer evaluations by themselves show mixed results, depending on individual students' beliefs about these processes. Therefore, the tutor's judgement on these processes is paramount. The tutor expresses his or her professional judgement in the form of a daily grade, which can range between 'A' (highest) to 'D' (lowest) and corresponds to the scores '4', '3', '2', and '1'. Inadequate performance or missing the day's lesson may also result in an 'F' grade (failure) that is equivalent to a score of '0'. The daily grade is always accompanied by written feedback to students, by the tutor, on various aspects of their learning and performance for the day.

In effect for each module, every student receives 16 daily grades and 4 test scores from each of the formal knowledge acquisition tests. The overall module grade is computed by combining the averages of both these assessment components, with the precise weighting between the two components varying from module to module. However, neither the daily grade component nor the knowledge test component ever accounts for more than 60% of the overall module grade.

1.3 ***Goals for this Study***

At the time this study was conceptualised, the literature reviewed (and presented in detail in Chapter 2) indicated that there was limited research that explained how a student's prior experience with mathematics affected his or her current experience of learning engineering. However, mathematics continues to be an integral part of engineering education, with many accreditation bodies requiring engineering programmes to show that that their students can apply knowledge and skill in mathematics (Patil & Codner, 2007). The literature in the area of engineering education did point to an implicit connection between mathematical skills and success in most engineering programmes, though the reason for this connection was rarely critically examined. In addition the PBL literature indicated that the intentions, strategies and processes adopted by students to direct and approach their learning, influenced how and what they learnt in a PBL setting (Blumberg, 2000; Hmelo-Silver, 2004).

The on-going shift in engineering from teacher-centred to student-centred approaches, such as PBL, further substantiates the need for research to explain how mathematics affects learning engineering. Research on the connection between mathematics and learning engineering should not be just anecdotal or limited to the educator's perspective, but it should also be from the perspective of the learners themselves.

Hence, the role of prior mathematics performance in affecting the way that engineering students approach learning within a PBL setting is the focus of this study. The goals of this study are to: (1) recognise the factors associated with prior mathematics performance that also influence how engineering is learnt; and, (2) develop a substantive theory or model of the educational experience of students who are perceived to be weak in mathematics and who are learning engineering. The significance of this study is its potential to improve the educational experiences of these students by contributing to knowledge in the area of engineering education, to policy considerations and to practitioner insight both in the immediate and wider engineering education context. Hence, an essential initial step in this study was to draft research questions that could appropriately guide the study in that direction. Such questions need to focus on both the factors that affect learning for the larger population of engineering students and the 'insider' points of view, such as the intentions and strategies of the minority of engineering students who have failed mathematics. Those questions are now outlined below.

1.4 ***The Research Problem and Research Questions***

Many laypeople, students and even some engineering faculty find it unfathomable that a student who is weak in mathematics can learn engineering. Given the situation described in the previous section, where students who have previously failed 'O'-level mathematics are enrolled in engineering programmes, this study has a unique opportunity to get to the heart of this issue. To this end, the main research problem that this study intends to address can be formulated as:

How are students who complete an engineering diploma in a dedicated Problem-Based Learning (PBL) setting affected by a prior mathematics failure; given the strong association between mathematics and learning engineering in the higher education literature?

This research problem was addressed by an empirical study conducted within the educational context, described in Section 1.2, between the years 2008 and 2010. This study drew upon both quantitative and qualitative methodological frameworks. The main means of quantitative data collection included a student survey and the demographic information of the entire engineering student population. The main means of qualitative data collection included in-depth semi-structured interviews, which persisted over two years, concurrent with data analysis.

The research design and methodology for this study are further outlined in Chapter 3. To assist with the examination of this research problem, four research questions have been formulated to guide field research in this area. Some of these research questions also guided the formulation of an aide-mémoire of specific data gathering questions to facilitate qualitative data collection (Punch, 2005) as discussed in Chapter 3. The four research questions are:

Research Question 1: What are the important factors and outcomes associated with learning engineering in a dedicated Problem-Based Learning (PBL) setting; and how does prior GCE 'O' Level mathematics performance affect these factors and outcomes?

Research Question 2: What do students, who have previously failed GCE 'O' Level mathematics, believe about the mathematics they have learnt; and how do they approach mathematics in the context of engineering education?

Research Question 3: What are these students' beliefs about engineering knowledge; how do they approach engineering problems in a dedicated PBL setting; and what are their expectations of the engineering profession?

Research Question 4: What is the grounded explanation for these students' experience of learning engineering; and how does this experience affect the educational processes and outcomes of these students?

These questions are at the heart of this study and the manner in which the thesis is organised to disseminate the research outcomes is described below.

1.5 ***Outline of this Thesis***

This first chapter has provided a brief orientation to the key features of the present study. There is an on-going shift in engineering education. This study has been located at the centre of this shift, within broader concerns about declining mathematics ability and the adopting of student -centred approaches to learning. This chapter also describes in detail the educational context in which the study was conducted, specifically the teaching and learning approach, programme design and assessment methods adopted. Importantly, the goals of the study, research problem and questions that guide this study were described. The rest of this thesis provides detailed reporting on all aspects of this study.

Chapter 2 provides a review of the relevant literature that informs the study. The literature involving current trends in higher education particularly in engineering education, student learning and Problem-Based Learning are thoroughly examined. The implicit and explicit connection between mathematics and engineering is highlighted, and a case is made for the need to investigate how learning in one domain affects the other.

Chapter 3 deals with methodological issues and provides details of the approaches to data collection and analysis. The research design is a mixed method design consisting of a baseline quantitative phase and an in-depth qualitative phase of research. The quantitative sample, survey instrument and statistical data analysis is described, followed by the qualitative strategy, participants, interview protocols and method of analysis. Finally, the ethical issues, such as participant protection and research quality controls are fully discussed.

The findings that emerged from the data analysis are presented in the next two chapters. Chapter 4 describes the quantitative findings, and Chapter 5 describes the initial qualitative findings. In Chapter 4 the key factors associated with learning engineering in the wider context of the institution are identified, and path models are built that show how these factors affect the process and outcomes of learning engineering. Chapter 5 focuses on the perspectives of students, in particular the way they conceptualise both mathematics and engineering. The interrelationship between conceptions of mathematics and engineering is demonstrated with evidence from the data.

Chapter 6 takes a more theoretically driven and interpretative perspective on the findings presented in the earlier chapters. It attempts to draws together both the quantitative and qualitative findings presented in the earlier chapters. A theoretical framework is established from the educational psychology literature. This framework is brought to bear upon the findings and a substantive theory of the effect of prior mathematics failure on participants' experience of learning engineering is proposed.

Chapter 7 summarises the major contributions of this study. It reflects on the findings of the present study, and discusses both the theoretical and practical implications and illustrates how the research questions have fundamentally been addressed. This reflection involves an assessment of the limitations of the present study and identification of future areas of research that arise from this study.

The appendices contain a number of other items not included in the body of this work, but they form part of the audit trail necessary for any trustworthy scientific inquiry.

Chapter 2 Literature Review

This chapter reviews recent and key literature relating to engineering education. In doing so it makes a case for, the need for research into how students who are perceived to be weak in mathematics, cope with an engineering diploma in a dedicated Problem-Based Learning (PBL) context. It seems that while this is an area of concern for educators and researchers in the practice of PBL, it is underdeveloped in the research. This will be evidenced in the paragraphs that follow.

The review of the literature is divided into two main sections. The first section, 'Research Regarding Engineering Education Pedagogies', reviews writings from an array of sources and notes how significant changes in society and technological advances in engineering practice have altered the shape of engineering education and its desired outcomes. It examines the various pedagogies that have been adopted in order to meet these outcomes, and reviews research on the efficacy of these pedagogies, especially in relation to higher education and to engineering. The second section focuses on 'The Role of Mathematics in Engineering Education'. It explores the perceived connection between mathematics and engineering, reviews research on issues regarding teaching mathematical skills to engineers, and explores what other authors say about the relevance of the mathematical skills being taught to students.

The literature reviewed shows what other researchers have recently discovered about engineering education, especially in regards to PBL, and in doing so also puts the proposed research in context with the current trends in the field. The range of perspectives provided, on the role of mathematics in learning engineering skills, is useful in conceptualising the study. Very little research on the role of prior experience of mathematics in learning in a PBL setting has been undertaken in the field of engineering education. One of the main issues in generalising about engineering education, from much of the literature reviewed here, is that the studies were conducted in various countries and mostly at an undergraduate level. It is acknowledged that the results may not be completely transferable to engineering education in the polytechnic. However, both contexts do share many similarities that allow for meaningful comparisons to be made. A positive aspect of this is that this study, of problem-based engineering education at a polytechnic level, is a unique contribution to the engineering education literature.

2.1 ***Research Regarding Engineering Education Pedagogies***

In the 20th century, the world changed at a more rapid pace than ever before. Engineers do not shy away from taking credit for this and a report by the U.S. National Academy of Engineering (Clough, 2004) claims that engineering through technology has forged an irreversible imprint on our lives, identity and the society, and it has made the world healthier, mostly safer and an extremely productive place. But what of the future of engineering education? Scientific and engineering knowledge is believed to double every 10 years (Wright, 1999). This geometric rate of growth reflects the apparent accelerating rate at which technology is being introduced and adopted. One may surmise that with humanity's growing numbers placing ever-increasing pressure on the resources of a shrinking world, the role of engineers is more important than ever. The creative and thoughtful use of engineering and technology will be vital for solving the problems of energy, food, transportation, housing, health care, communication, manufacturing, education, environmental protection and for fulfilling all the other requirements of modern life (National Academy of Engineering, 1991).

Pertinent to the education of future engineers, is the claim by Augustine (1994) that few students can absorb all the necessary technical and non-technical knowledge as well as the requisite practical experience in four years of higher education. Furthermore, only approximately half the students entering universities in the United States of America (USA) as engineering majors complete their degree requirements (Wulf & Fisher, 2002). In engineering education, the cause is almost self-evident; the explosion of technology in recent times and need to prepare students for the varied engineering careers that already exist today.

According to Florman (1987), engineering education in the 21st century should endeavour to make students more aware of the complex interrelationships between engineering and industrialised society (including the natural environment), encouraging and preparing them to assume stronger and more visible roles as responsible engineers in society and as productive citizens. From the sheer number of journal papers published in the last decade, it is obvious that, what engineering students are learning and how they are taught are key issues on the minds of educators and researchers.

Overwhelmingly, the body of research in this field mirrors the shift in pedagogical approaches seen in several engineering programmes around the world (e.g., Aalborg University on Denmark, Eindhoven University in the Netherlands, Glasgow University in Scotland, Manchester University in England, McMaster's University in Canada, Monash University in Australia, and Republic Polytechnic in Singapore) (Jonassen, et al., 2006). These institutions deliver a significant amount of their engineering curricula via inductive student-centred pedagogies, in contrast with the deductive teacher centred model of the classroom based teaching and learning processes, that have been characteristic of engineering education in the past fifty years (Holt & Solomon, 1996).

2.1.1 *Desired Outcomes of an Engineering Education*

Today's engineering industry measures an engineer's worth not only from his or her breadth and depth of disciplinary knowledge, but also from his or her experience in developing personal and professional skills, ability to work with other engineers and with colleagues from other disciplines (Crawley, Malmqvist, & Östlund, 2007). Engineers tend to work in environments that continually attract change and innovation (Bransford, 2007). At the same time, an engineer is also expected to address modern-day challenges such as sustainability or sustainable development, which have emerged of late as an increasing priority for engineers and consequently engineering education (Mann, Walther, & Radcliffe, 2005).

Few will deny that for an engineer to meet these diverse requirements, problem solving is an important skill. Research (Reid, 2006; von Kampen, 2005) has validated the importance of this skill in the workplace and, Kim and King (2004) affirm that problem solving is essential for engineers. It has been argued (Smith, Sheppard, Johnson, & Johnson, 2005) that the reason for this being an essential skill is that engineering or technology graduates are usually paid to solve problems that do not relate exactly to the material presented in a chapter, or do not have a single 'correct' answer that one can find at the end of a book. ABET (the recognised accreditor for college and university programmes in applied science, computing, engineering, and technology in the USA) specifies the abilities to identify, formulate, and solve engineering problems as essential learning outcomes for any engineering programme (Besterfield-Sacre et al., 2000). In fact, since engineers are hired, retained, and rewarded for their abilities to solve workplace problems, engineering students should learn how to solve similar problems (Clough, 2004; Jonassen, et al., 2006).

As straightforward as this premise seems to be, teaching students to solve problems is not as direct and simple as it may appear. From the literature, it seems that process of problem solving itself is not well understood. In a review of over 150 published basic strategies for problem solving, Woods (2000) found that most strategies seem to be based on a personal style instead of upon research about the process of problem solving. Little research has been done on the cognitive and attitudinal dimensions of problem solving. Furthermore other research (Wu, 1996) suggests that personal and technological problem solving styles may well be separate and distinct. The tendency in education has been to employ the term "problem solving" generically and the results of Wu's study suggests that such generalisation may be inappropriate.

Another valid consideration is the nature of genuine engineering problems encountered in the workplace. A qualitative study (Jonassen, et al., 2006) conducted with 106 practicing engineers found that workplace engineering problems are substantively different from the kinds of problems that engineering students most often solve in the classroom. This study identified the following ten attributes of engineering workplace problems. Workplace problems:

1) are ill-structured and complex;
2) possess conflicting goals;
3) multiple resolution methods exist;
4) have non engineering success standards;
5) have non engineering constraints;
6) usually are unanticipated problems;
7) involve distributed knowledge;
8) require collaborative activity systems;
9) experience aids in finding appropriate solutions to workplace problems; and,
10) can be represented in multiple forms.

Engineering educators in the past have taken for granted that learning to solve well-structured problems while studying positively transfers to solving ill-structured problems in the workplace. Conversely, recent research has shown that learning to solve well-structured problems in a classroom setting does not readily transfer to ill-structured problems in the workplace (Cho & Jonassen, 2002; Dunkle, Schraw, & Bendixen, 1995; Hong, Jonassen, & McGee, 2003). That is, learning to solve problems where the parameters of the problems are specified by the problem itself, does not enable graduates to solve complex and ill-structured workplace problems (Jonassen, et al., 2006). In order to solve workplace problems, Jonassen (1997) believes that students must develop adequate conceptual frameworks, and apply those frameworks in defining and then solving complex ill-structured problems. However, other research (Downey, Lucena, Moskal, & Parkhurst, 2006) suggests that engineering problems are not only solved in different ways, but are also defined in different ways in dissimilar cultures. Accordingly, it is evident that establishing a generic pedagogical approach to teach problem solving skills is easier said than done. Nevertheless, this is the crux of one of the challenges facing engineering education today.

While the ideal pedagogy for teaching engineering is still an issue of contention, there has been better progress made on the objectives and desired outcomes of engineering education (Besterfield-Sacre, et al., 2000). Identifying of the key objectives for engineering education is an important step, and it has generated much discussion in the literature. For example, the application of the current ABET engineering learning outcomes (Felder & Brent, 2003), a working definition of engineering and engineering work (Sheppard, 2004), and the results of the Engineer of 2020 project (Clough, 2004) all mirror ideas about what educational objectives a student needs to meet to function as an effective engineer.

A common way to represent the nature of understanding of each objective in the literature is Bloom's taxonomy of educational objectives (Bloom, Englehart, Furst, Hil, & Krathwohl, 1956). Bloom's taxonomy was initially created as a means of methodically categorising educational objectives in a way that aids communication among educators. Bloom recognised six categories of cognitive learning outcomes, namely knowledge, comprehension, application, analysis, synthesis and evaluation. A survey of recent literature in the field of engineering education (Fink, Ambrose, & Wheeler, 2005; Olds, Moskal, & Miller, 2005; Parsons, Caylor, & Simmons, 2005; Prince & Felder, 2006; Safoutin et al., 2000; Turns, Atman, Adams, & Barker, 2005) found that Bloom's taxonomy is a useful and often adopted method to represent learning objectives.

Much of the literature reviewed calls for engineering education to adapt to a rapidly changing world and student needs (for example Bryant, 2006; Maskell, 1999). Despite the increasing pressure, engineering programmes are crowded and so making room for new developments is difficult (Burns & Chisholm, 2005). Furthermore, engineering education tends to be conservative in its pedagogical approaches, curriculum and institutionalised attitudes. Engineers have traditionally born the responsibility for ensuring that engineering designs function safely and reliably, and perhaps this is the historical basis of this conservatism. Discipline and rigor are unquestionably necessary in engineering, but as Seymour and Hewitt (1994) have pointed out this is counterproductive when taken to such an extreme that many talented and capable students become alienated or just lose interest in continuing with an engineering education.

2.1.2 *Deductive Approach to Engineering Education*

Engineering has traditionally been taught via deductive teacher centred pedagogies, embodied by traditional lecture based teaching. In this approach, the instructor introduces a topic by lecturing on general principles, then uses the principles to derive mathematical models, shows illustrative applications of the models, gives students practice in similar derivations and applications in homework, and finally tests their ability to do the same sorts of things in exams (Prince & Felder, 2006). In the deductive approach, students solve problems by learning to translate relationships about unknowns into equations, solving these equations to find the value of the unknowns, and confirming the values found to see if they satisfy the original problem (for example Rich, 1960). However, learning to solve classroom problems does not necessarily prepare engineering students to solve workplace problems. Furthermore this linear process implies that solving problems is a procedure to be memorised, practiced, and familiarised (Jonassen, et al., 2006).

Perhaps the traditional lecture based approach has been the basis of mass education for centuries, simply because there was no alternative. Today there is much criticism of lecture-based teaching as a means for information dissemination and learning. Hills and Tedford (2003), claim that the Internet has inundated the world with explicit knowledge and it has supplied the means of managing and organising that knowledge. They assert that implications for education are profound and the Internet has exposed the traditional didactic procedure of teaching by lectures as the "fraudulent, inefficient instrument of learning it always was" (p. 18). The efficacy of this approach is brought further into doubt by evidence (King, 1994; Loverude, et al., 2002; Mestre, 1994) that suggests that students who sit passively in lectures for an entire course fail to replace their prior misconceptions with new knowledge, and the conceptual difficulties they have when they enter a course are likely to endure if their difficulties are not addressed specifically. In addition, Loverude, Kautz, and Heron, (2002) in their study of student understanding of the first law of thermodynamics (a fundamental concept in science and engineering), found that traditional approaches fail to provide opportunities for integrating new and old knowledge. Lectures may lead to memorisation of factual information but often do not do well in eliciting understanding of complex concepts.

Göl, Nafalski et al. (2005), suggest that quality outcomes in terms of both teaching and learning engineering can be achieved by treating the process more liberally and shifting at least some of the responsibility for the student's learning onto the student. They say that this would reward the students with the satisfaction of knowing that they take on real challenges associated with engineering problem solving. For the teachers the gratification is in knowing that they have somewhat contributed to the students' achievements. Further criticism for the traditional deductive method can be recognised in an established principle of educational psychology, that is, that people are for the most part motivated to learn things they clearly recognise a need to know. If this principle is adhered to then just telling students that they will need certain knowledge and skills some day is not a very effective motivator (Albanese & Mitchell, 1993). Taking a less critical stance, Box and Liu (1999) argue that engineers cannot stick to the deductive processes alone but must learn to alternate between inductive and deductive methods of learning, using physical understanding or engineering models to enlighten the experimental approach and then update their understanding and models based on data.

2.1.3 *Inductive Approaches to Engineering Education*

While Prince and Felder (2006) assert that inductive teaching and learning is preferable to deductive teaching and learning, they acknowledge that ‘inductive teaching and learning’ is an umbrella term that encompasses a range of instructional approaches. They describe the inductive approach as beginning with a specific set of observations or experimental data to interpret, a case study to analyse, or a complex real world problem to solve. As the students try to analyse the data or scenario and solve the problem, they generate a need for facts, rules, procedures, and guiding principles, at which point they are either offered the needed information or helped to discover it for themselves. The common variants of this type of instructional approach are inquiry learning, problem-based learning, project based learning, case based teaching and discovery learning (Felder & Brent, 2004).

According to Bateman (1990) inquiry learning begins when students are presented with questions to be answered, problems to be solved, or a set of observations to be explained. Students work in small groups on instructional modules that present them with information or data, followed by leading questions designed to guide them toward formulation of their own conclusions. The instructor’s purpose is to facilitate this process, by working with student groups if they need help and addressing class wide problems when necessary. According to Prince and Felder (2006) if this approach is implemented well, the students should learn to "formulate good questions, identify and collect appropriate evidence, present results systematically, analyse and interpret results, formulate conclusions, and evaluate the worth and importance of those conclusions" (p. 9). Inquiry based approaches, though not predominant, are used to some extent in engineering education (Buch & Wolff, 2000; Stahovich, 2002).

Problem based learning (PBL) starts when students encounter an open ended, ill-structured, authentic problem and work in teams to identify learning needs and develop a viable solution. As in inquiry learning, the instructors act as facilitators rather than primary sources of information (Barrows, 1996; Norman & Schmidt, 1992; Woods, 1994). Ideally in PBL, students should: investigate knowledge concepts within diverse contexts (Spiro, Feltovich, Jacobson, & Coulson, 1992); connect new information with prior knowledge (Barrows & Tamblyn, 1980; Boud & Feletti, 1997); try out the use of knowledge in various contexts; determine the viability of their conceptions (von Glasersfeld, 1995); and, come to value how they personally construct knowledge and become meaning makers (meta cognitive) (Mayer, 1996). Engineering problems in PBL vary considerably in scope, from single-topic single-discipline problems that can be solved in a day (Alwis & O'Grady, 2002) to multidisciplinary problems that may take an entire semester to solve (Yuzhi, 2003).

In project based learning students are given an assignment to carry out tasks that lead to the creation of a final product (Dym, et al., 2005). In engineering terms, this can be a design, a model, a device or a computer simulation. The conclusion of the project is normally a written and/or oral report summarising the procedure used to produce the product and presenting the outcome. Instructors can either be fairly directive in choosing projects, to help maintain a focus on course and curriculum objectives, or they can allow students the independence to choose their own project formulations and strategies, which increases their motivation (Prince & Felder, 2006). De Graaf and Kolmos (2003) define three types of projects that differ in the degree of student autonomy:

- Task projects, where student teams work on projects that have been defined by the instructor, using largely instructor prescribed methods.
- Discipline projects, where the instructor defines the subject area of the projects and specifies in general terms the approach to be used, but the students identify the specific project and design the particular approach they will take to complete it.
- Problem projects, where the students have nearly complete independence to choose their project and their approach to it.

Project based learning involving the use of small projects within individual courses, progressing to a final-year project is a common feature of undergraduate engineering programmes (Dym, et al., 2005; Mills & Treagust, 2003).

In case based teaching, students analyse case studies of past or hypothetical situations that involve solving problems and decision-making. In the context of engineering education, Kardos and Smith (1979) originally defined an engineering case study as, “an account of an engineering activity, event or problem containing some of the background and complexities actually encountered by an engineer” (as quoted in Prince & Felder, 2006, p. 17).

This approach is relevant to the various fields of education (such as engineering, law and medicine) that makes extensive use of cases for professional training.

Discovery learning is an inquiry based approach in which students are given a problem or a set of observations to explain, and then work in a largely self-directed manner to complete their assigned tasks and draw appropriate inferences from the outcomes, “discovering” the desired factual and conceptual knowledge in the process (Prince & Felder, 2006). In the purest form of this approach, instructors set the problems and provide feedback on the students' efforts but do not direct or guide those efforts. What instructors are more likely to do is apply a variation of discovery learning that involves the instructor providing some guidance throughout the learning process (Spencer & Jordan, 1996). Once this is done, one can argue that the differences between discovery and problem based learning tend to disappear. Laboratory classes and problem sets are the general examples of discovery learning in engineering programmes (McCowan, 2002).

2.1.4 *Efficacy of Problem-Based Learning*

While these inductive approaches defer, they share an essential characteristic, that is, each of these approaches supports learning how to solve a problem. Based on the literature reviewed, it would appear that the emphasis on problem solving in the field of engineering has increased. Understandably, the efficacies of these inductive approaches are something that academics and educators have been very concerned with of late. However, measuring the efficacy of the various instructional methods is not as straightforward as it seems.

Every instructional approach consists of more than one element and it also affects more than one learning outcome (Norman & Schmidt, 2000). According to Prince (2004), a broad range of outcomes should be considered. However, comprehensive data on how an instructional approach influences all the various learning outcomes is often not available. Where data on multiple learning outcomes is available, it can include results that are mixed, and if an approach works or not becomes a matter of interpretation. Prince claims that another significant problem is that many relevant learning outcomes are simply difficult to measure and even when data on higher-level outcomes are available, reported results are often misinterpreted. In addition, instructors may have varying degrees of experience and skill with whichever approach they adopt, causing two different instructors using the same approach in the same class to get different results (Prince & Felder, 2006). Adding to the complexity, engineering student populations also vary significantly. They vary in distributions of, among others, gender, ethnicity, age, experience, motivation to learn, learning styles and levels of intellectual development (Felder & Brent, 2005). Considering these difficulties, it is not surprising that published studies report both positive and negative outcomes for inductive approaches.

Of the various inductive approaches to teaching and learning engineering discussed in the previous section, the bulk of the research literature has been focused on PBL and project based learning. Though both pedagogical approaches are similar in several respects (as discussed above), there are differences in the way they have been traditionally implemented. For example, in project-based learning, the outcome is the focal point of the

assignment and finishing the project for the most part requires application of previously acquired knowledge. On the other hand, PBL requires acquiring new
knowledge to solve a problem, and the solution is often less essential than the knowledge gained in obtaining it. In other words, the emphasis in project based learning is on applying or integrating knowledge while that in PBL is on acquiring it (Prince & Felder, 2006).

In practice, however, the difference between the two approaches is not necessarily that distinct, and intuitions have lately taken up approaches that include aspects of both of them (Mills & Treagust, 2003). Take for example the University of Aalborg, Denmark where project work makes up approximately half of the curriculum. This is one of the first project based engineering curriculum in the world, which began with the formation of the university in 1974. In the first-year of instruction, task and problem projects dominate. Task and discipline projects dominate the second and third years, and problem projects dominate the fourth and fifth years (de Graaff & Kolmos, 2003). The current approach at Aalborg is a hybrid of problem based and project based learning, with the projects being more about acquiring knowledge than applying it (de Graaff & Kolmos, 2003). Another noteworthy example of a hybrid problem/project based curriculum at the University of Louvain, Belgium (Prince & Felder, 2006).

Thomas (2000) in his review of research on project based learning claimed that the findings resemble those found for PBL, with similar or slightly better performance on tests of content knowledge, and notably better performance on assessments of conceptual understanding and ability to solve problems that require conceptual understanding as compared with traditional approaches. More recently, Mills and Treagust (2003) reviewed published evaluations of project based learning programmes in engineering and came to the conclusion that the findings are similar to those for problem-based learning in medicine. That is, relative to traditionally taught students, students who participate in project-based learning are more motivated, demonstrate better communication and teamwork skills, have a better understanding of issues of professional practice and know how to apply their learning to realistic problems. The negatives were that students may be less competent in engineering fundamentals, and some of them would be perhaps unhappy over the time and effort necessary for projects and the interpersonal conflicts they experience in teamwork, especially with teammates who do not put in their share of the work. In addition, if the project work is conducted completely in groups, the students may be less ready to work independently.

In respect of PBL, individual studies have found a positive effect on a number of areas. These include, among others, skill development (Albanese & Mitchell, 1993; Vernon & Blake, 1993), understanding the interconnections between concepts (Gijbels, et al., 2005), deep conceptual understanding (Dods, 1997), ability to apply appropriate meta cognitive and reasoning strategies (Chung & Chow, 2004), and class attendance (Lieux, 1996). A longitudinal study of the efficacy of the McMaster PBL programme in chemical engineering established its advantage over the traditional approach to education in the development of key process skills (Woods, et al., 1997). PBL has also been shown to encourage self-directed learning (Blumberg, 2000) and the adoption of a meaning oriented approach to learning, as opposed to a memorisation based approach to learning (Coles, 1985; Felder & Brent, 2005; Norman & Schmidt, 1992).

Duchy, Seers et al. (2003) published a meta-analysis of the efficacy of PBL on knowledge acquisition and development of problem solving skills. They identified 43 empirical studies of the effects of PBL in tertiary (college) students. Seven of the studies analysed found a positive effect of PBL on knowledge acquisition and 15 found a negative effect, with a weighted average effect size and 95 per cent confidence interval of -0.223 (±0.058). However, when true randomised tests are included; the negative effect of PBL on knowledge acquisition was found to be insignificant, and when the assessment of knowledge is carried out sometime after the instruction was given, the effect of PBL is positive. The implication is that students may acquire more knowledge in the short term when instruction is by the traditional approach but students taught with PBL retain the knowledge they acquire for a longer period. For the development of problem solving skills, 14 studies found a positive effect and none found a negative effect, and the weighted average effect size was 0.460 (±0.058). This positive effect of PBL on skill development remains constant, regardless whether the assessment is concurrent with the instruction or delayed.

Prince (2004) examined several meta analyses of PBL specific to engineering. He separately considered the effects of its constituent approaches, which were, active learning, collaborative learning, and cooperative learning. He concluded that the strongest positive effects of PBL related to the favourable student and faculty responses to the method and to a small but robust improvement in students' skill development. While a statistically significant effect was not found in relation to improvement of academic achievement as measured by exams, there was evidence that PBL enhanced students' retention and ability to apply material.

A major theme in the literature is the possible trade-off between knowledge acquisition and skill development, or alternatively, between breadth and depth of content coverage when PBL is used. De Graaf and Kolmos (2003) observe that students may be expected to reach a level of analytical understanding through problem-based work that cannot be attained in traditionally taught classes. In attempting to reach this level of understanding, they might experience subject area gaps and should be equipped to fill in such gaps when a need arises. Perrenet, Bouhuijs et al. (2000) make a similar claim explicitly related to engineering education. They claim that if PBL is implemented in a way that allows a lot of self-direction by students, what those students learn may not necessarily correct the misconceptions that encumber understanding of essential engineering concepts. This could in turn interfere with the students' ability to apply their learning to new problems in a professional setting. They also note that unlike medicine, which has an encyclopaedic structure, the knowledge structures of engineering tend to be hierarchical. Engineering students occupied in self-guided PBL might easily ignore or circumvent critical topics, which could interfere with future learning of important content.

In addition to this, PBL facilitators must also be aware that PBL makes students take on unfamiliar levels of responsibility for their own learning. Most students also experience project management problems and interpersonal conflicts that commonly occur when students are required to work in teams. Hence, students who are new to PBL may require more support initially (Tan, Parsons, Hinson, & Sardo-Brown, 2003). Because of these factors, many students are unreceptive to PBL when they initially encounter it. This had been found to be true of all inductive or student-centred approaches (Felder & Brent, 1996). However, in support of adopting this approach, a number of studies offer confirmation that most students who experience PBL ultimately come to favour it over the traditional approach (Dods, 1997; Hung, et al., 2003; Vernon & Blake, 1993).

2.2 ***The Marriage of Engineering and Mathematics***

The connection between engineering and mathematics is something that has concerned engineering educators for over a hundred years (Waldo, 1904). Even at the turn of the last century educators were discussing the correlation between mathematics and engineering knowledge (Comstock, 1905), the outcomes of teaching mathematics skills to engineers (Jackson, 1905) and evaluating the methods by which mathematics was taught (Slocum, 1909; Townsend, 1908).

Today it is still customary for engineering programmes to include a substantial amount of mathematics, a fact traditionally justified through the usefulness of mathematics in the analysis and resolution of many technological problems. Kumar and Jalkio (1999) claim it is widely recognised by engineering educators that students in engineering programmes should be better prepared in mathematics to successfully complete courses. This belief is not limited to educators. A survey of 514 engineering students found that one of the prime reasons for choosing to study engineering was a belief that good mathematics skills qualified them for an engineering career (Anderson-Rowland, 1997).

In education, the role of mathematics in engineering has long been emphasised, but the opposite viewpoint also holds true. Fernandez and Pacheco (2005), have shown that the historically the development of engineering has influenced mathematics, as much as the reverse. The following quote from them beautifully captures their insights into the mathematics-engineering connection: "Coming to an end, we are about to rediscover the classical problem of engineering: how to master and control the forces nature offers to those who venture to use them. Along the long path in the search for partial solutions to this problem (of mastering the forces of nature), engineering and mathematics have always walked together and, more often than not, in a braided fashion" (2005, p. 89).

2.2.1 *The Mathematics Problem*

In the mid-1990s, numerous reports confirmed the severity of 'the mathematics problem' currently faced by engineering education. In 1995, the report 'Mathematics Matters in Engineering' (The Institute of Mathematics and Its Applications) was published on behalf of various institutions of engineers and mathematicians. This report concluded that, "Too many graduate engineers are perceived to be deficient in mathematical concepts and fluency" (p. 27). Around the same period another report for the Engineering Council in the United Kingdom (UK), 'The Changing Mathematical Background of Undergraduate Engineers' (Sutherland & Pozzi, 1995), specifically sought to address the declining mathematical strength of recruits to engineering courses. One of the findings of this report was that the mathematical understanding of first-year undergraduate engineers was weaker in 1995 than it was 10 years previously. Some researchers (Edwards & Edwards, 2003) claim that this general decline in undergraduate mathematical ability shows little sign of improving.

In addition to this, other work (McDonald, Mander, & Taylor, 2004; Mustoe, 2001; Mustoe, 2002; Shaw & Shaw, 1997) has shown additional problems associated with the diversity of intake. Today, students enter engineering studies with inhomogeneous mathematical backgrounds, beliefs and study experiences, and this produces a mismatch with traditional engineering programmes. Apprehension has been expressed about the ability of such students to cope. While the bulk of the literature is concerned with student entering undergraduate programmes in universities, it is likely the same findings would apply in respect to students with similar demographics entering an engineering programme in polytechnics.

A good deal of research has been conducted that affirms the importance of a good understanding in the initial mathematics course and its correlation with success in engineering programmes (Budny, et al., 1997; LeBold, et al., 1989). Shaw and Shaw (1997) found some correlation between performance at university and mathematics grade for A level students, but no correlation for BTEC (Business and Technology Education Council) students in the UK. They attributed this to a range of other variables, such as the type of educational institution attended before university, entry qualifications, the usefulness of various teaching methods and the difficulty found with specific subject areas. Other published results (Page & Page, 2001) claim strong correlation between mathematical skill in general and overall performance, but much less correlation between arithmetical skill and general performance for undergraduate students.

Armstrong & Croft (1999) conducted a study to identify the learning needs in mathematics of entrants to undergraduate engineering programmes. They concluded that urgent attention needs to be paid to pre-university (for example, General Certificate of Education Ordinary level and General Certificate of Education Advanced level) qualifications in mathematics, and until this is done it will be necessary for universities to adapt their courses and make special provision to address the lack in basic mathematical skills of some undergraduates. They also suggested that further research needed to be undertaken to identify the sources and validity of perceived problems in teaching, learning and assessment of these students who “lack sufficient fluency and skill in basic mathematical techniques” (p. 70).

McCray, DeHaan, & Schuck (2003) found that in part because of poorly taught introductory undergraduate mathematics courses, a ‘mass defection’ has occurred away from the sciences and engineering. From 1993-2000, engineering post graduate programmes in the USA have experienced a decrease in enrolment by an average of 25 per cent. This defection is representative of engineering programmes in many countries and at various levels, including Singapore at polytechnic level. Could mathematics be the main obstacle?

Year 2000 was the World Mathematical Year. Grünwald and Schott (2000) in their paper on ‘Challenges in Revolutionising Mathematical Teaching in Engineering Education under Complicated Societal Conditions’ described mathematics as thus: “Mathematics contains serious logical reasoning and cannot be dealt with in 20 seconds; it needs concentration. Thus, mathematics seems to be an unimportant and boring school subject for the general public that they either failed or barely passed. Typical is that the first mathematical equation in a text reduces the potential number of readers by 50%, while the second one kills it” (p. 235).

Hills and Tedford (2003), explore failure and retention in engineering programmes. They use a model of learning, the virtuous cycle of learning (see Figure 2.1), to describe how engineering students learn in an undergraduate programme. All five steps in this cycle are essential for its completion and failure of one leads to failure of them all. They claim the step most easily ignored because of its human connotations is that of motivation, yet this is at the core of the learning process. An engineering student may encounter 20 or more of such cycles in their undergraduate experience. If they are sequential, then the failure of one may jeopardise the rest. They assert that the most common cause of failure within the undergraduate engineering curriculum is a defeat in one or more cycles of mathematics.

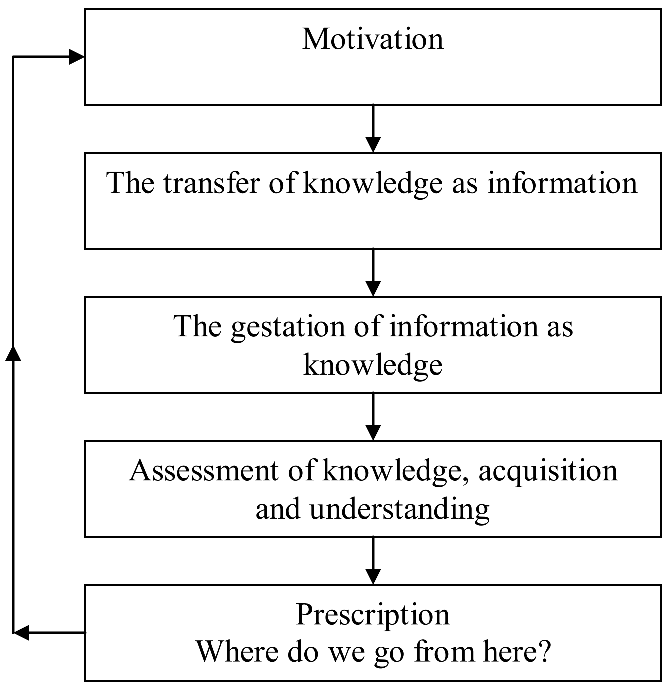


Figure 2.1 - The virtuous cycle of learning (adapted from Hills & Tedford, 2003)

French, Immekus et al. (2005) found that for students to persist in engineering, a strong academic background (in mathematics and science), achievement of good grades, and most importantly academic motivation are needed. They claimed that there remained much variance to be accounted for in the explanation of student success and persistence, and suggested continued exploration of how additional variables might contribute to students' academic success and persistence within an engineering programme.

2.2.2 *Teaching Engineering Student's Mathematics*

In an effort to address this problem, some engineering institutions are providing other forms of support to students. One such institution, Loughborough University (UK) has offered support to engineering students with non-traditional mathematics backgrounds, in the form of a key-skills preparation course in mathematics and engineering, with moderate success (Bamforth, Crawford, Croft, & Robinson, 2005). Another initiative in the UK is HELM (Helping Engineers Learn Mathematics), a three-year (2002 to 2005) curriculum development project undertaken by a consortium of five universities (Loughborough, Hull, Reading, Sunderland and Manchester). This projects aims to enhance the mathematical education of engineering undergraduates by the provision of flexible learning resources such as computer-aided learning courseware and computer-aided assessments. Students in a focus groups (Davis, Harrison, Palipana, & Ward, 2005) felt that this approach helped to focus their attention on the material being covered and thought that it should be extended to other modules.

Based on the literature, there seems to be various perspectives on exactly how mathematics should taught to engineering students. Kumar and Jalkio (1999) think that success in engineering depends heavily on the application of mathematical techniques to real world problems. Therefore, there should be an increased use of engineering examples in mathematics courses to enhance the familiarity of concepts in mathematics. Kolari and Savander-Ranne (2000) assert that for engineering education to meet the wide requirements of industrial life, educators must recognise that mathematical solutions are only a tool and should set demands on the student in a versatile, rational and fitting way.

Chee (2001) in an exploratory study on the views of polytechnic students in Singapore on PBL as a mode of learning Mathematics, found that students generally felt positive towards PBL and it had a positive impact on their attitudes towards learning Mathematics. He also found that they acquired content knowledge and other skills such as teamwork, self-directed learning and thinking. Niklasson, Christie et al. (2002) described an integrated approach to teaching mathematics with chemical engineering, and reported progress in learning involving:

- deeper understanding of basic phenomena;
- improved relevant problem solving skills;
- an engineering approach to attacking problems and also the critical interpretation of the results;
- the development of the student's ability to work independently; and,
- the student's appreciation of the main and basic fundamental aims of their education.

A case study by Roberts (2003) on motivating engineering students to do mathematical proofs, found that even though engineering students are exposed to a significant amount of mathematics, they often do not learn "the art of doing mathematical proofs" (p. 231). Robert claims that a better understanding of how to prove a result can greatly enhance the student's ability to learn. Other recent research (Dana-Picard & Steiner, 2004) claims that professional engineers usually solve mathematical problems using technology, by using a single one-step 'high-level' command of available computer packages to obtain the solution immediately. However, the same authors assert that in an engineering mathematics course, the educator should decompose the solution process into elementary steps and reinforce each step by a 'low-level' usage of computer-aided solutions. They state that this approach is essential in order to provide the future engineer with the conceptual insight into the solution process.

The increased use of mathematical software and computer-aided solutions in the engineering profession and in engineering education is another issue that has occupied educators. Colgan (2000) describes the integration of the mathematical software MATLAB into the teaching of core mathematics to first-year university engineering students. Niklasson and Irandoust (2001) suggest engineering education needs to be modernised and that new tools of calculation, especially Computational Mathematical Modelling (CMM) and Computer-aided Design (CAD) can be used to build bridges between subjects, schools and courses previously considered to be separate. Niklasson, Christie et al. (2002) say that the importance of CMM for technological progress is growing constantly, as there are higher demands on the accuracy and complexity of engineering models. Schott (2005) claims that new mathematical tools influence the methodology and the contents of engineering education, but reasonable integration of mathematical software systems in engineering education demands that the students have a solid knowledge of mathematical basics. Therefore, the modern mathematics in engineering courses has to include an element of computer-based mathematics, but it should not be completely dependent on it. He states student must know both the new perspectives and the new risks of using mathematical software tools. Finally, Molina and Trujillo (2005) have shown that improvements, in the ability of engineering students to interpret solutions graphically and numerically, can be achieved by proper use of mathematical software.

2.2.3 *The Relevant Mathematical Skills for Engineering*

The literature seems to support the idea that mathematics skills are helpful to successfully completing any engineering course. However, various engineering fields and careers require different skill-sets and it is equally important for educators to consider if the mathematics taught to engineering students is relevant. Contrary to the usual affinity for mathematics in most engineering fields, some practicing software engineers have argued that mathematics is not that important in software engineering education since practitioners do not use it explicitly (Glass, 2000). Even in traditional engineering fields others have reported (Reed, 2001), based on career experience, that the over emphasis of mathematics in education is largely irrelevant. However, the same author separates clearly numerical competence as a requirement quite separate from mathematics. Henderson (2003) asserts that all engineering disciplines involve mathematical modelling and analysis but the methods, tools, and degree of precision differ between traditional and software engineering. He goes on to elaborate that traditional engineers use continuous mathematics primarily in a computational mode for modelling, design, and analysis, while software engineers usually use discrete mathematics and logic in a declarative mode for specifying and verifying system behaviours and for analysing system features.

According to Chisholm (2003) the recent concern of educators with how to effectively teach mathematics to engineering students is less critical than discovering the kind of mathematical competency most useful for engineering. He states that mathematics skills should be closely correlated to the requirements of the many varied programmes now available and not taught on the basis that mathematics is essential for all engineers. Lakoma (2002) suggested that the changing and wide application of information technology, in all fields of our life, means that mathematical knowledge becomes necessary in almost every domain. He believes that there is an urgent need of a new mathematical literacy for engineers and it is necessary to consider the processes of mathematics learning at tertiary level from the epistemological perspective and to investigate students' ways of mathematical thinking.

Progressive institutions are starting to restructure their courses to meet these new expectations and pressures. PBL becomes an attractive approach for such changes and increasingly, it is beginning to replace traditional lecture based learning. PBL in engineering education will require that mathematics be introduced at various stages as progress is made on the problem or project (Fuller, 2002). This will call for flexibility on the part of educators and a variety of methods for providing learning support on mathematical topics, which is required for the varied problems and projects. The mathematics component of engineering programmes will also need to reflect this change to PBL. The increasing use of mathematics software and technology to enhance learning in engineering education indicates that there is a need to undertake a major reassessment of the mathematics education of engineering students. Fuller and Jorgensen (2004) believe that this reassessment is necessary to ensure that the mathematics education provided for engineering students is compatible with the changes taking place in modern engineering practice.

2.3 ***Conclusion from Literature Review***

Inductive student-centred approaches, the most commonly practiced being PBL, are gaining a foothold in engineering education. While PBL has been established in medical education (Albanese & Mitchell, 1993; Barrows & Tamblyn, 1980), it is a relatively new form of instruction for engineering. The issues based on the literature of PBL in engineering are similar to the issues raised by educators in other fields that have adopted PBL (Hung, et al., 2003). These issues are: (1) depth versus breadth of curriculum; (2) higher-order thinking versus factual knowledge acquisition; (3) long-term effect versus instant learning outcome; (4) traditional roles of educators versus the role of PBL facilitators; and, (5) initial discomfort versus their positive attitudes.

While most of the empirical research in the field was positive, it is difficult to make generalised conclusions on the efficacy of PBL in engineering for all students due to the following reasons:

- When comparing PBL to traditional approaches, it is rarely defined exactly what is ‘traditional’.
- PBL in engineering education is often not the main instructional approach. Many institutions who claim to practice PBL have adopted a hybrid approach that combines PBL with ‘traditional’ approaches.
- The literature reviewed reflects various countries, types of educational institutions, student entry qualifications and academic backgrounds, and vastly different measures of the dependent variables.

However, one common feature that seemed to stand out in PBL and in most inductive approaches for that matter was the need for students to engage in collaborative learning, as described by Gokhale (1995). In fact Göl and Nafalski (2007) argue that collaborative learning is linked to many educational approaches including, but not limited to, PBL. They also make the case, that in order to achieve the goals of engineering education getting students to engage some form of collaborative learning is the natural and inevitable choice.

There are some gaps in the literature in regards to PBL in engineering. There is definitely a lack of a clear distinction between project-based learning and PBL, both of which require student collaboration and are increasingly common in engineering education. Even though PBL has been internationalised and there has been much research various international contexts, there is a dearth of international collaborative research on PBL in engineering education. In particular how the various engineering educators implement PBL given varying institutional resources and cultural norms. Likewise, it was also challenging to locate scholarly work that compared the implementation and efficacy of PBL at various educational levels. There was little in the way of comparison between using PBL for engineering education at a diploma level and degree level, which would have been of particular interest to the current study.

Reverent to the research questions, the literature revealed an implicit connection between mathematical skills and success in engineering programmes. However, changing requirements, use of new technology and new instructional approaches in engineering programmes validate the need for research into the mathematics education of today's engineering students. In order to improve the learning experience and outcome for students, a first step would be the development of an understanding of the 'insider' point of view. A survey of the recent literature revealed only one study that examined the learning experiences of engineering students in PBL (Du, 2006). However, this study focused on the gender aspects of a problem-based engineering education.

In Chapter 1, the main research problem was introduced: **'How are students who complete an engineering diploma in a dedicated Problem-Based Learning (PBL) setting affected by a prior mathematics failure; given the strong association between mathematics and learning engineering in the higher education literature?'**

The literature reviewed in this chapter validates the need to solve this problem. From this comprehensive literature review, it seems that the perspectives and strategies of how academically weak students cope with PBL have been under-researched. Particularly with regard to mathematically weak students and how they cope with an engineering education. In the following chapter, the research design and methodology used to conduct this study and thus address this research problem is presented and explained.

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Chapter 3 Research Design and Methodology

This chapter explains the systematic process of inquiry that was undertaken in this study. It describes in detail the research design and methodologies that have been employed, including the instruments, participants, data collection and analysis procedures, ethical considerations and quality controls. As discussed in the previous chapter, the research focused on the extent to which prior mathematics performance affected the process and outcomes of learning engineering; and, the beliefs, intentions and strategies of engineering students who performed poorly in mathematics. The methodological approach was a mixed method of quantitative and qualitative techniques as appropriate for the collection of data in order to best respond to the nature and intent of the research problem. This chapter consists of four sections. The justification for the overall research design is presented in the first section. The second section includes detailed explanation of the quantitative data collection and analysis procedures, as well as the rational for using this approach. The third section expands on the qualitative aspects of the study and explains the logic of collecting and analysing qualitative data. The final section deals with the ethical considerations that should underpin any research, such as the quality controls built into the study and human participant protection.

3.1 ***Overall Research Design***

The two major paradigms in educational research are quantitative and qualitative research methods. Both of these methods each have their own epistemological beliefs, their own relative strengths, weaknesses, and their own militant defenders. It was likely this, which led to the now largely resolved war between these two paradigms (Golafshani, 2003). The clash of these two paradigms has brought forth many new and exciting ways of doing research, which can neither be placed squarely in the quantitative nor qualitative camp (Johnson & Onwuegbuzie, 2004). Though some pundits might think otherwise, educational research is all the richer because of this spectrum of research strategies that are available to the academic community.

Quantitative research is concerned with the quantity or measurement of some phenomenon. The basis of quantitative research is to explain reality in terms of variables, done by measuring these variables and studying the relationship between them. This approach has proven itself repeatedly in various areas of social science research where the variables can be straightforwardly identified or where there exist a number of theories that explain the processes that occur (Punch, 2005). Explanation has long been a cornerstone of scientific knowledge and has a rich tradition in the quantitative methods. However, quantitative research has typically been directed at the verification of explanatory theory rather than the generation of such theory in educational research. There are nevertheless exception to this, as various writers have pointed out (Brewer & Hunter, 1989; Hammersley, 1992).

Qualitative research aims to produce rounded understanding of phenomena in context-specific settings. Patton (2002, p. 39) claims that this kind of research is appropriate for a "real world setting [where] the researcher does not attempt to manipulate the phenomenon of interest". Done well it has the power to explain a particular social situation rather than just describe it. Qualitative data is often described in the literature as “rich” or “thick description" (Wolcott, 1994, p. 156) and can be in many varied forms, such as data in the form of any words, sounds and visuals. Qualitative research methods are, by comparison to quantitative methods, a complex, multi-faceted, evolving and contested field. Qualitative research in education is in fact an umbrella term, which encompasses a great variety of methods, which are based on a number of distinctive epistemological beliefs and perspectives. However, various authors have made attempts to identify the common features of qualitative research per se (Miles & Huberman, 1994; Tesch, 1990; Wolcott, 1992). One of common characteristic of many methods in the qualitative paradigm is the axiom that that the researcher's viewpoint plays a central role in the research process. This is based on the acceptance that research facts and researcher's value judgments or interpretations of the research cannot truly exist separately in any form of research, as the researcher always chooses what to study based on his or her value judgments. As the researcher's unique viewpoint is central in the research, one criticism of qualitative methods is that it is hard to generalise to other research settings (Peshkin & Eisner, 1990). Though quantitative methods have gained a permanent foothold in social science research, some qualitative research may still suffer from the negative outward perception of not being as well formulated and as coordinated as quantitative research, especially when it comes to the methods of analysing data (Kvale, 1996, p. 180).

In choosing a research strategy, each research situation needs to be analysed and understood within its own context and no one strategy should be regarded as the most suitable or applicable because of a prior commitment to a certain paradigm (Punch, 2000). The process of learning engineering has always been a complex mix of cognitive and social activity (Dym, 1999) and PBL as an approach to learning engineering further emphasises this mix (Dym, et al., 2005). The aim of this research was to make sense of this mix by; firstly, by verifying which of the different aspects of learning engineering were affected by mathematics skills and; secondly developing a substantive theory that explains the processes through which, students who are weak in mathematics may deal with learning engineering. Therefore, to truly understand how engineering was learnt and in particular appreciate how mathematics skills affected learning engineering in this multifaceted learning environment, one has to investigate the situation from multiple perspectives and through various methodological lenses.

This study investigated the impact of mathematics skills on learning engineering in a PBL setting through the views of two such methodological lenses, a student survey and in-depth interviews. The student survey was designed to generate quantitative data that allowed analysis of the broad learning environment and the identification of important factors that are involved in learning engineering. The in-depth interviews of students generated rich qualitative data that allowed analysis of students' beliefs, intentions and strategies to realise their learning goals. This type of research that combines quantitative and qualitative methodologies is often labelled 'Mixed Method Research' (Johnson & Onwuegbuzie, 2004) and has been argued for as a pragmatic and integrated approach to educational research inquiry (Ercikan & Roth, 2006).

The purpose of the research design was to achieve two closely connected goals of this study. Firstly, to understand the impact of mathematics knowledge and skills on the experience of learning engineering in the wider engineering population, and secondly to develop substantive theory about the educational experience of students who failed mathematics taking into account their beliefs intentions, strategies and educational outcomes. To satisfy the first goal a Baseline Quantitative Study was conducted. This was carried out concurrently with the selection of students for in-depth interviews to collect rich data in an In-depth Qualitative Study. Studying the interviews allowed detailed analysis of the students' perspectives, hence contributing to the second goal of the research design. These two aspects of the study are described in the sections that follow.

3.2 ***Baseline Quantitative Study***

The baseline quantitative aspect of the study helped to establish whether or not the prior mathematics performance of students truly was a major factor in determining how and what students learnt in their engineering courses. It also allowed for a broad analysis of the learning environment and identification of the factors that most influence the outcomes of engineering education across the entire institution. Quantitative methods, as employed in this study, are undoubtedly the best way to describe the reality of learning engineering in terms of factors and to measure the relationship between these factors (Punch, 2005, p. 203). There were two main sources of quantitative data: (1) demographic information of the entire engineering student population as of end 2009, such as 'O' Level entry scores, current Grade Point Average (GPA), age, year of study and gender; and, (2) student responses from a validated survey instrument.

3.2.1 *Study Population and Survey Participants*

Participants in this study were selected from a population of approximately 3000 engineering students. All participants were enrolled in three-year engineering diploma programmes during the second semester of the 2009/2010 academic year. The latter half of 2009 was recognised as the best time to conduct the survey as all students, by then, had experienced at least one semester of education at the polytechnic. The entire engineering student population was invited to participate in the study by completing an optional student survey online on their experiences of learning engineering. Students were contacted via an email, which explained the purpose of the survey. They were then allowed one month to respond to the survey at their convenience. In pilot testing, all students could complete the survey within 15 minutes.

In total, 1745 valid responses were received, representing students from across the entire engineering cohort. Of these 528 responses were excluded as they were from students who were admitted into the polytechnic without completing the GCE ‘O’ Level. These were mostly overseas students and students from the Institutes of Technical Education. The remaining 1217 responses were matched with demographic information such as ‘O’ Level entry scores, current Grade Point Average (GPA), age, year of study and gender that were obtained from the Office of the Registrar at the polytechnic. Table 3.1 displays the frequencies of these 1217 responses by year of study and prior performance in ‘O’ Level mathematics.

Table 3.1

Cross-tabulation of year of study and 'O' Level mathematics performance of survey participants

			'O' Level Mathematics		
			Fail	Pass	Total
Year of Study	1	Count	205	324	529
		% within Year of Study	38.8%	61.2%	100.0%
		% of Total	16.8%	26.6%	43.5%
	2	Count	80	322	402
		% within Year of Study	19.9%	80.1%	100.0%
		% of Total	6.6%	26.5%	33.0%
	3	Count	29	257	286
		% within Year of Study	10.1%	89.9%	100.0%
		% of Total	2.4%	21.1%	23.5%
	Total	Count	314	903	1217
		% of Total	25.8%	74.2%	100.0%

As illustrated in Table3.1 , over one quarter of the respondents to the survey failed 'O' Level mathematics with the largest percentage enrolled in the first-year. Of the respondents 818 (67.2%) were male and 399 (32.8%) were female. They ranged in age from 16 to 30, with the median and mode age being 18.

3.2.2 *Survey Instrument*

The survey instrument used was adapted from the validated APPLES (Academic Pathways of People Learning Engineering Survey) instrument that was developed and validated over a period of over a period of five years, and used by the U.S. National Science Foundation funded Academic Pathways Study (Chen et al., 2008). As part of this study, the survey was administered to over 4500 undergraduate engineering students at 21 U.S. engineering colleges and schools in the spring of 2008. The initial comprehensive set of analyses was recently completed on the complete APPLES dataset, and was published in September 2010 (Sheppard et al., 2010). One of the main objectives of the APPLE Survey was to explore the broad based educational experiences of students at a range of types of engineering schools. The APPLES instrument was chosen for the current study because of its suitability for various types of engineering schools, and its ability to elicit from students perspectives on their educational experiences. While this survey instrument has been extensively validated, it was designed for a U.S. context. Therefore, minor modifications had to be made to some items in the survey to make it appropriate for the local context, and statistical tests had to be conducted to verify if the modified instrument was a reliable as the original. The modification and reliability testing of the survey are discussed in subsequent paragraphs.

Initially 24 constructs were identified, from the original APPLES instrument, which were relevant to this study. This consisted of 16 multi-item variables measuring concepts relating to factors that influence students' intentions to study engineering and eventually, to continue studying or working in an engineering field. In addition, eight single item variables were also selected to be additional descriptors of the student experience. All of these selected variables are listed in Table 3.2.

Table 3.2

The 24 variables measured in the student survey

Variables		
Motivation (Financial)	Motivation (Parental Influence)	Motivation (Social Good)
Motivation (Mentor Influence)	Motivation (Intrinsic, Psychological)	Motivation (Intrinsic, Behavioural)
Confidence in Mathematics and Science Skills	Confidence in Professional and Interpersonal Skills	Confidence in Solving Open-ended Problems
Perceived Importance of Mathematics and Science Skills	Perceived Importance of Professional and Interpersonal Skills	Curriculum Overload
Academic Disengagement—Liberal Arts Courses	Academic Disengagement—Engineering-related Courses	Frequency of Interaction with Instructors
Satisfaction with Instructors	Academic Persistence	Professional Persistence
Exposure to the Engineering Profession	Knowledge of the Engineering Profession Currently	Involvement in Engineering Related Activities
Involvement in non-Engineering Extracurricular Activities	Research Experience	Overall Satisfaction with Collegiate Experience

Items in the survey that were associated with these variables were modified to suit the local context and items that were deemed unsuitable were removed. The original survey instrument consisted of 100 items, which was reduced to 74 items in the final survey administered to students. All of these items required responses on a four or five-point scale. The modified survey was pilot tested with a group of six engineering students and further changes were made based on their feedback ((see Appendix A – Item-by-item Modification to the Original APPLES Instrument).

Since the original survey items were modified it was important to verify the reliability of the 16 modified multi-item variables. The measure of reliability that was selected was Cronbach's Alpha, which indicates the extent to which the items in a scale can be treated as measuring the same latent construct. This is also known as the internal consistency of the items. Generally speaking, Cronbach's Alphas of 0.6 and higher are considered acceptable levels of internal consistency, this threshold is arbitrary and an Alpha value of 0.7 or above is preferable. The Alpha values for all 16 items of this survey were above 0.7, indicating a good level of internal consistency. Single item variables were not included here as internal consistency is only an issue with multiple item variables.

Table 3.3 lists the 16 multi-item variables of the student survey, along with measures of internal consistency, the Cronbach's Alpha scores of the modified and original surveys. The outcome of this analysis determined that all of the variables could be used in subsequent analysis.

Table 3.3

Reliability of the multi-item variables of the student survey compared to the original APPLES instrument

Variable	No. of Items	Cronbach's Alpha of Modified Student Survey	Cronbach's Alpha of Original APPLES (Sheppard, et al., 2010)
Motivation (Financial)	3	0.78	0.81
Motivation (Parental Influence)	2	0.79	0.83
Motivation (Social Good)	3	0.80	0.77
Motivation (Mentor Influence)	4	0.84	0.77
Motivation (Intrinsic, Psychological)	3	0.88	0.75
Motivation (Intrinsic, Behavioural)	2	0.78	0.72
Confidence in Mathematics and Science Skills	3	0.85	0.80
Confidence in Professional and Interpersonal Skills	6	0.85	0.82
Confidence in Solving Open-ended Problems	3	0.73	0.65
Perceived Importance of Mathematics and Science Skills	3	0.87	0.80
Perceived Importance of Professional and Interpersonal Skills	6	0.83	0.82
Curriculum Overload	5	0.79	0.82
Academic Disengagement—Liberal Arts Courses	4	0.81	0.75
Academic Disengagement—Engineering-related Courses	4	0.76	0.71
Frequency of Interaction with Instructors	3	0.70	0.70
Satisfaction with Instructors	4	0.85	0.79

3.2.3 *Statistical Data Analysis Procedures*

All quantitative data gathered from this survey were first analysed using SPSS 16.0 (Statistical Package for the Social Sciences version 16.0), to determine the important underlying factors that affected how engineering was being learnt. Where two groups were being compared (such as when exploring differences between male and female students), t-tests were conducted to determine if the groups were statistically different from each other. When more than two groups were compared (such as when exploring differences between students in different years of study) Analysis of Variance (ANOVA) procedures were carried out. Post-hoc LSD (Least Significant Difference) tests were performed when data were homogeneous, while post-hoc Games-Howell tests were performed when data were not homogeneous. As a measure of the strength of association between the independent and dependent variables (such as when exploring the association between 'O' Level mathematics performance and intrinsic motivation) the statistical significance and effect size were reported. Statistical significance was taken to be *p* values of less than 0.05, meaning that there was at least a 95% chance that the result could not have happened by chance. The eta-squared (η^2) index was taken as a measure of effect size. The meaningfulness of this measure is dependent on the area of investigation. However, in social science investigations η^2 of 0.01, 0.06 and 0.14 are by convention, interpreted as small, medium and large effect sizes, respectively (Cohen, 1992).

After key variables that affect how students learn engineering were identified, Path Analyses were conducted to determine the relationship between these variables and their association with the outcomes of engineering education. Path Analysis, a form of Structural Equation Modelling, is a statistical technique used to examine possible causal relationships between two or more variables. It has been primarily used to understand relative strengths of direct and indirect relationships among a group of variables. Path Analysis was selected as it allows mediating variables in the pathway ($X \rightarrow Y \rightarrow Z$). The pathways in a path model represent a hypothesis of how various variables relate to each other and how they may affect certain outcomes of an engineering education. This type of analysis allowed for a data grounded hypothesis to be generated based on the large number of variables being examined in this study. For example, it might be hypothesised that prior mathematics performance does not have a direct effect on current academic performance in engineering. However, it may directly affect motivation to study engineering, confidence in solving open ended-problems and perceptions about the engineering context, which may in turn have an effect on current academic performance. A Path Analysis presents correlational data between variables and the relative sizes of the path coefficients in the resulting path diagram. Therefore, it can show if any hypotheses generated are supported by the data.

The SPSS software plug-in, Amos 16.0, was employed to aid with the Path Analysis. In Path Analysis, all path models have to be shown to fit with the data in order to be accepted. The Amos 16.0 software makes it simpler to generate, modify and verify multiple models in order to find the best model based on the data available. The software enables verification of the path model's fit with the data, by automatically calculating for several model fit indices. For evaluation of model fit, Meyers, Gamst, and Guarino (2006) recommend considering the Comparative Fit Index (CFI) and the Root Mean Square Error of Approximation (RMSEA). A value of 0.95 or greater for the CFI is deemed as an acceptable fit, while for the RMSEA, a value of 0.08 or less indicates good fit. As a further measure of fit, the model also should have a low chi-square (χ^2) score relative to degrees of freedom (*df*). There is no consensus regarding an acceptable ratio for this statistic but values typically range from as low as 2.0 to as high as 5.0 (Hooper, Coughlan, & Mullen, 2008). For this study, all of the mentioned criteria were used to determine if the models generated should be accepted or not.

3.3 ***In-Depth Qualitative Study***

The purpose of the quantitative portion of the study, described in the previous section, was to understand the factors associated with poor mathematics ability that affected learning engineering. The purpose of the in-depth qualitative study, on the other hand, was to develop a substantive theory; that described how students who were weak in mathematics dealt with this weakness and coped with learning engineering. A qualitative analysis allowed the beliefs, intentions and strategies of students to be closely examined in order to more closely unpack aspects of their learning experiences that were not revealed by the survey and quantitative analysis. In this study, one-on-one semi-structured in-depth interviews were the main form of qualitative data collection.

The grounded theory method was the qualitative research strategy selected to achieve the goals of this portion of the study. Grounded theory was originally formulated by Barney G.

Glaser and Anselm L. Strauss in their landmark study on dying patients (Glaser & Strauss, 1966, 1968). Since then it has evolved substantially and been used extensively in many areas of inquiry including, business, education, health and sociology. Grounded theory is well accepted and is likely the "most widely employed interpretive strategy in the social sciences today" (O'Donoghue & Punch, 2003, p. 382). This research method is one that is concerned with situations resulting from the interaction of individuals and society and can discover patterns of "action and interaction between and among various types of social units" or actors (Strauss & Corbin, 1994, p. 278). A theory generated by this method is meant to be discovered, developed, and provisionally verified through methodical data collection and analysis of data relating to a phenomenon being studied (Glaser, 1992). The reasons for selecting grounded theory methods over other qualitative methods in this particular study were:

1. An important aspect of this research study was to examine the way students' beliefs, intentions and strategies affected the process of learning engineering. Grounded theory methods specifically include analysis of process, were process is taken to be the researchers way of explaining or accounting for change. Within the grounded theory framework Strauss and Corbin (1990, p. 143) describe the term process as "the linking of sequences of action/interaction as they pertain to the management of, control over, or response to a phenomenon."

2. Grounded theory methodology "directly connects macroscopic issues to the phenomenon under investigation" (Punch, 2000, p. 103). In this study broader contextual issues, such as the findings from the baseline quantitative study that have

been shown to influence how these students interpret and deal with learning engineering, could be taken into account and explained in the theory that was developed.

3. Grounded theory analysis is very much enhanced by ‘theoretical sensitivity’ (Glaser, 1978; Strauss & Corbin, 1990), the ability to perceive variables and relationships. This ability consists of the professional knowledge, the personal experiences and the research experience that the researcher has gained. Theoretical sensitivity aids in the development of categories, as well as the relationships of categories to each other and will lead to the emergence of themes, which can then be connected to other data. The researcher taught various science and engineering subjects for six years in the polytechnic where this study was conducted. Because of this experience, the researcher could connect themes that emerged from the interviews to his daily observation of students in a natural setting. Hence, the choice to use grounded theory methods was supported by the researchers’ immersion in the research area (engineering education), knowledge of the context (a polytechnic where PBL is the dedicated instructional approach) and familiarity with the student participants.

3.3.1 *Sampling Strategy*

The population for this study was all the students who did not receive a passing grade for the GCE ‘O’ level Mathematics and were enrolled in any of the engineering diploma programmes at the polytechnic of interest in 2009. Due to a general decline in interest in engineering programs among students nationally, and the relative newness of the polytechnic where this study was conducted, a surprisingly large number of these students did end up in engineering courses. It was estimated that up to one-quarter (¼) of students in engineering courses either failed or did poorly in mathematics at the time of this study.

In grounded theory the sampling strategy, data collection and analysis are inextricably bound together. After the initial sample and data collection, all data collection and analysis happen concurrently. All subsequent data collection is guided by the outcomes of the analysis of the data from the previous sample. Typically, in an idealised grounded theory approach data collection and analysis carries on until the researcher is unable to develop categories further in terms of their properties and dimensions, regardless of the amount of new data collected. Glaser (1992) calls this ‘theoretical saturation’. According to Glaser and Strauss (1967) the actual number of participants studied is less essential than the potential of each participant to add to the researcher’s understanding in the area being studied.

However, in light of the limited time and resources available to the researcher it was more reasonable to work within a clearer set of parameters so that the aims of the research were achievable. The approach taken in this study was Stainback and Stainback’s (1984) idea of ‘modified analytic induction’. Stainback and Stainback explain this as tightly defining a population based on the number of cases that the researcher has the resources to cope with and essentially basing the theory and testing of the theory only on those cases. The researcher consequently has to be cautious when claiming the theory is inclusive beyond the defined set. Using the principle of 'modified analytic induction', the intention was to limit the number of student participants in the study to below 10. This number was the upper limit of what was deemed manageable by the researcher, considering factors such as access to the participants and time taken for verbatim transcription of the data collected.

Initially the student admission data, of all students enrolled in the polytechnic of interest in 2009, were obtained from the Office of the Registrar. The database was filtered to identify the entire population of students who did not pass the GCE 'O' level Mathematics and were enrolled in any of the engineering diploma programmes. An email was sent to all of the students in this population to give students a brief outline of the study and for them to indicate their willingness to participate in the study. Students were then selected from the small group who responded positively to the invitation to participate. The strategy in sampling from this group was to choose students who would potentially have the most to contribute the research problem and the immerging themes in the research. For example, the researcher initially conducted two pilot interviews with first-year engineering students. However, it was evident from the interviews that these first-year students were generally unable to comment deeply on learning engineering, as they did not yet have enough exposure to the field of engineering. (Engineering students in the first-year generally study broad based subjects such as 'Computing and Mathematical Methods' and 'Basic Science' before moving on to more applied engineering subjects in the second and third-year.) Therefore, these two pilot interviews were excluded from the final analysis and henceforth the remaining students enrolled into the study were from the second and third-year. This type of sampling is an essential part of the grounded theory method and is called 'theoretical sampling' in the literature (Glaser, 1978; Strauss, 1987).

Each student was contacted either by telephone or through a face-to-face meeting with the researcher, both for introductory purposes and to briefly discuss the study. Following this initial conversation a consent letter was sent to the students' homes explaining the purpose of the study, expectations of participants and issues of confidentiality. In the weeks following, the student was contacted again via telephone, email or a face to face meeting, in order to confirm that the consent forms had been signed and to set up an interview time with each student. Interviews were one-on-one and each interview was audio taped with the students' permission. In total nine students participated in the interviews for this study. These students are introduced in the following section, Section 3.3.2 (Interview Participants). The student participants were interviewed one at a time and some analysis was conducted on each interview before proceeding to the next interview. This allowed subsequent data collection to be guided by the outcomes of the analysis of the data from the previous interview.

The main method of data collection in this phase of the study was semi-structured interviews. The details of the interview protocols are discussed in Section 3.3.3 (Interview Protocols). The findings of the baseline quantitative study also helped to inform the analysis of the interviews and contributed directly to the substantive theory. There is no formal directive that limits collecting data in a grounded theory approach to research to qualitative data, although the literature published with the application of the grounded theory method has been almost exclusively with qualitative data. However, to quote Glaser "The distinction, and hence the wrestle, between qualitative and quantitative data is not relevant for grounded theory. If the reader can accept that all is data … [then] grounded theory is a general method that can be used on all data in whatever combination" (Glaser, 1998, p. 42).

3.3.2 *Interview Participants*

This study was conducted at a large tertiary institution that awards a three-year diploma in various disciplines. At the time of the study, approximately 14000 students were enrolled at this institution in various diploma programmes, of which approximately 2500 were enrolled in engineering programmes. Only engineering students in the second and third-year of their studies, who had not obtained a passing grade in 'O' Level mathematics, were considered for the in-depth interviews. As described in the previous section, the students were initially contacted via an email requesting their participation. Ten students were selected from those who indicated their interest, however one student did not turn up for the interview and when contacted decided to withdraw from the study.

The participants were from three different engineering diploma programmes: (1) Diploma in Biomedical Electronics; (2) Diploma in Communication and Automation Electronics; and, (3) Diploma in Supply Chain Management. The Diploma in Supply Chain Management had a less intensive mathematics component than the other two diplomas programmes, however only one participant was from this diploma programme. The other eight participants who were enrolled in the more electronics focused diploma programmes would have experienced a very similar curriculum to one another. The participants ranged in age from 19 to 25, and there were two females and seven males. All participants were Singaporean; four were ethnically Malay, three were ethnically Chinese and two were ethnically Indian. In addition, five participants were in their second-year and four participants were in their third-year.

The nine student participants, without whom this study would not have been possible, are introduced below. The participant's actual names have been replaced by pseudonyms to protect their confidentiality and specific details about their background have been purposefully excluded for the same reason. Participants are introduced in the order they were interviewed; they are Vick, Tamir, Fizal, Andi, Rachel, John, Lan, Cai and Diana.

1. **Vick** was the first student interviewed and one of the first to respond to the email invitation to participate. He is ethnically Indian, 20 years old and in the second-year of the Diploma in Biomedical Electronics. He was possibly the most eager participant of the nine and actually helped to publicise the study to his friends. He admitted to struggling in his engineering programme, but he felt that he was coping better than many of his peers. Vick was very active in non-engineering extracurricular activities at the polytechnic. He was a member of three clubs including the student council.

2. **Tamir** is ethnically Malay, also 20 years old and in the second-year of the Diploma in Communication and Automation Electronics. In contrast to Vick, he claimed his main reason for participating was because he was struggling with PBL and he wanted to express how he felt. He claimed that he was not really active in extracurricular activities in campus, though he did play some soccer on the weekends. His immediate goal was to complete his engineering diploma and move on to something unrelated to engineering.

3. **Fizal** is ethnically Malay, a third-year student in the Diploma in Communication and Automation Electronics and 21 years old at the time of the interview. He was looking forward to graduating and he wanted to participate in this study because he wanted to share how hard it was for him to reach this point. He felt that despite being in his third-year there was a lot he did not know about engineering. One of his main preoccupations, other than graduating, was to get fit for his National Service due after graduation.

4. **Andi** is ethnically Malay, 20 years old and a second-year student in the Diploma in Communication and Automation Electronics. He did poorly for both Mathematics and English at the 'O' Level and he felt that getting into any polytechnic was a rare opportunity for him. While he found PBL and engineering hard, he said that he was coping well. He came across as very motivated to get good grades in his engineering diploma. He claimed his social life was too busy for him to get involved in extracurricular activities in campus.

5. **Rachel** is ethnically Indian and was 22 years old during the interview. She was in the final-year of the Diploma in Biomedical Electronics. Her reason for participating in the study was to help inform others like her what to expect of an engineering diploma. She felt that she did not know what engineering was at all when she chose the course. As one of the few girls in her diploma programme, she felt there were both positives and negative to being female and studying engineering. She generally liked PBL but felt it was too hard to use it for all the subjects.

6. **John** is ethnically Chinese, 21 years old and in the final-year of the Diploma in Communication and Automation Electronics. Of all the participants, he was the most enthusiastic about PBL. He was a committee member of the student led PBL interest group and a PBL ambassador (conducting outreach activities) to secondary schools. He felt it ironic that he ended up in engineering having failed mathematics. Despite his enthusiasm for PBL, he felt that it was not a big impact on the way he learnt engineering.

7. **Lan** is ethnically Malay. He was 22 years old and in the final-year of the Diploma in Communication and Automation Electronics. Lan spent two years at the Institute of Technical Education before enrolling in the polytechnic. Though he still struggled with learning engineering in the polytechnic, he felt that this experience gave him an edge over his peers. He participated in the study because he felt that it was an avenue to feedback about his course and experiences.

8. **Cai** at age 25 was the oldest student participant. He was in his final-year of the Diploma in Communication and Automation Electronics. He took a longer route than most of his peers to get to the polytechnic. He completed both an Institute of Technical Education certificate and his full time National Service before enrolling. At the time of the interview, he was among the top five GPA performers for his entire cohort. He came across as very confident, though he claimed that he still struggled with the more mathematical aspects of engineering. Cai's conceptions of engineering reflected his maturity and were very developed when compared to most of than the other participants' conceptions.

9. **Diana** was the final and youngest student interviewed. She is ethnically Chinese, 19 years old and in the second-year of the Diploma in Supply Chain Management. She admitted she never liked mathematics and was glad that her engineering diploma programme had a lesser emphasis on mathematics than others did. She came across as somewhat ambivalent about her diploma though she claimed that she was coping well. She participated in the study because she wanted to help improve the school.

3.3.3 *Interview Protocols*

Denzin and Lincoln (2003, p. 698) describe interviews as "not neutral tools of data gathering but active interactions between two (or more) people leading to negotiated, contextually-based results". Interviews are increasingly being recognising by researchers as one of the most powerful ways we have of understanding others. Interviews, as a means of data collection in the social sciences, may be structured, unstructured or semi-structured. While structured interviews have formalised, limited set questions, semi-structured interviews are more flexible, allowing new questions to be brought up during the interview as a result of what the interviewee says (Kvale, 1996). As previously, mentioned, semi-structured in-depth interviews, which were transcribed verbatim, were the main form of qualitative data collection in this study.

As with the quantitative data, the qualitative data were also intended to answer the main research problem as described in Chapter 1. For the purpose of guiding the semi-structured interview process, and keeping the interviewer on track, the research questions were initially operationalized in form of the following guiding questions:

1. *What have these students learnt about mathematics?*
2. *How do these students use mathematics in their engineering courses?*
3. *What are these students beliefs about the nature engineering knowledge?*
4. *How do these students believe that engineering knowledge is acquired?*
5. *How do these students go about learning engineering?*
6. *What affects these students approach to learning engineering?*
7. *What do these students think they achieve through their engineering studies?*

These guiding questions were further broken down into an aide-memoire of questions that were developed to help direct the interviews even more specifically (see Appendix C – Aide-Memoire of Questions for Interviews). The aide-memoire was a general list of questions that were intended to be discussed during the interview (O'Donoghue & Punch, 2003, p. 17).

In this study, this document was used flexibly to allow for the discussion of relevant issues that were raised by the interviewees. The aide-memoire was given to the student participants a week before the initial interview to allow students to reflect on the questions that have importance for them.

In keeping with grounded theory methods, where data collection and analysis are an iterative process, each interview also provided supplementary data about the concepts that emerged from the initial analysis of the transcripts of the previous interviews. Students received a transcript of their interview after each interview stage and they were contacted to discuss the accuracy of the transcription as well as any other insights that they had since their interview. Memos were made throughout this process to capture any insights that occurred to the researcher during analysis, or were offered by the students during interviews. These memos were an integral part of the data collection and analysis. Miles and Huberman (1994) suggest using memos as a sense-making tool. They suggest that researcher created memos help tie together different pieces of data into a cluster, often showing that those data are illustrations of a general concept. Thus, as an early step in analysis memos were written to combine ideas that emerged from the interpretation interview transcripts and observation field notes and video transcripts. The initial ideas that emerged from early analysis were sketched on paper using simple diagrams and tables. The directions emerging from the analysis of the first set of data guided the subsequent set of data collection. This cycle of alternation between data collection and analysis continued until the new data no longer showed new theoretical elements but verified what has already been found (Punch, 2005, p. 158).

3.3.4 *Grounded Theory Data Analysis Procedures*

The aim of grounded theory analysis is to find a core category at a high level of abstraction that accounts for what is central in the data (Punch, 2005). This approach to analysis of data uses a systematic set of procedures to develop a theory through induction (general to specific) (Glaser, 1992). On the other hand, it is also in some ways deductive (specific to general) as the researcher must move back and forth in his or her thinking to examine the generalisations and attribute specific meaning throughout the analytic process (Chenitz & Swanson, 1986; Strauss, 1987). The strength of a grounded theory method is that it uses the capacity of abstract theory to go beyond the empirical data, and links phenomena that initially appear unrelated. It does this while being 'grounded' in what is central in the data (Punch, 2005).

At the heart of grounded theory analysis, is coding. Coding is a way in qualitative research to explore bits of information in the data, and look for similarities and differences within these bits to categorise and label the data (Patton, 2002). Glaser has described the code as "the essential relationship between data and theory" and coding as a process that, "gets the analyst off the empirical level by fracturing the data, then conceptually grouping it into codes that then become the theory which explains what is happening in the data"

(Glaser, 1992, p. 55). Strauss and Corbin (1998) are more informative about how to go about the process of coding. They divide the process into three phases, namely ‘open coding’, ‘axial coding’ and ‘selective coding’. These phases will be explained in detail in the sections that follow. Even though each of these phases are conceptually distinct operations, they need not necessarily take place in separate stages as the researcher will often alternate between the three modes of analysis. For example, ‘open coding’ and ‘axial coding’ may be employed jointly in the early stages of the study, and they may occur jointly with ‘selective coding’ as the study progresses further. In this study, these coding procedures were applied flexibly and in accordance with the changing circumstances throughout the period of data gathering, analysis and theory generation.

Throughout the coding process, memos have been used to aid the analysis of the data. Memos are researcher’s detailed notes of ideas about the data and the codes generated, and they represent the development of codes from which they are derived (Glaser, 1978, pp. 83-92). In this study, all through the process of coding, the analysis of the data was checked with other researchers, to make sure that no major possibilities were ignored and that nothing was forced into the data, and to give robustness to analysis. The students’ feedback was also sought, especially with respect to the naming of categories. Given the vast number of codes that can be generated during analysis practical hints in the literature suggest the use of computer software applications, to manage and code data, categorise codes and identify themes that emerge (Tesch, 1990). The software NVIVO 8.0 was used for this purpose in this study. Bazeley (2007) claims that the NVIVO software application provides researchers with tools to manage data and ideas, as well as query, graphically model and report from the data. She also argued that the tools provided by NVIVO are method free and can be used for wide range of methodological approaches.

A. <u>Open Coding</u>

The first coding of data is called open coding, and it starts when data collection begins. The researcher does not wait for all data to be collected, because the results of the coding influence the collection of the data. Glaser (1978, p. 56) describes open coding as, the "fracturing of data into analytic pieces which can then be raised to conceptual level". The researcher codes the data into categories and properties of categories. Codes are defined by Strauss and Corbin as (1990, p. 61) "conceptual labels placed on discrete happenings, events, and other instances of phenomena". As certain common categories present themselves to the researcher repeatedly, they were labelled in the researcher's memos to be explored further in subsequent data collection and analysis.

Whilst looking at the data, Glaser believes that the researcher needs to ask 'neutral' questions in order to help avoid forcing, to allow concepts to emerge and findings to have relevance (Glaser, 1978, 1992). Glaser identified a number of neutral questions. These questions could be: 'What is this data a study of?'; 'What category or what property of what category does this incident indicate?'; 'What is actually happening in the data?'; and, 'What is the basic social psychological process or social structural process that processes the main problem that makes life viable in the action scene?' These types of questions are asked while constantly comparing incident to incident and coding and analysing. The coding itself can be done in any way as long as the researcher is able to keep track of the codes. Some possible strategies are noting in margins, writing on cards or using a computer software program (Flint, 2005).

The defining rule of the constant comparative method of grounded theory is applied during this process, that is “while coding an incident for a category, compare it with the previous incidents in the same and different groups coded in the same category” (Glaser & Strauss, 1967, p. 106). Open coding happens very rapidly at first with the creation of a large amount of codes. However, as the codes are compared to determine if they fit, in the end they should saturate and their true significance is found among the other codes.

B. Axial Coding

Axial coding interconnects the first order categories created from open coding, producing propositions. Axial coding is describe by Chenitz and Swanson (1986, p. 125) as organising, clarifying relationships between categories, and developing theoretical links between them. Strauss and Corbin (1990) describe it as putting data back together in new ways by making connections between the coded categories. Concepts are connected by; the examination of causes and consequences; a series of ideas sharing the same meaning; intervening conditions that either facilitate or constrain action/interaction strategies; and seeing things as either different aspects of a category or as parts or stages of a process (Punch, 2005, p. 210). As with open coding, the constant comparison method was employed to discover and verify these connections. The researcher has to move between inductive and deductive thinking, as properties suggested by the data are verified against other incidents in a "constant interplay between proposing and checking" (Strauss & Corbin, 1990, p. 111).

As a direct consequence of the axial coding process, the theoretical properties of a category start to become clear and eventually a core category, which the majority of other categories seem connected to, emerges from the data. From that point onwards, further exploring of the issues and ideas occurs primarily around the core category. This leads into the third and final phase of coding.

C. Selective Coding

The term 'selective' is used in selective coding because in this stage the researcher has to deliberately select one aspect as a core category and concentrate on it, with the objective of integrating and pulling together the developing analysis. Strauss (1987, p. 33) describes selective coding as "coding systematically and concertedly for the core category". Glaser (1978, p. 61) describes it as delimitating coding "to only those variables that relate to the core variable in sufficiently significant ways to be used in a parsimonious theory". In other words, the researcher in selective coding looks for the conditions and consequences that are related to the core process. The researcher must develop theoretical memos to elaborate the category in terms of its properties and relate the other categories to it. Selective coding also reveals those categories that require the additional collection of data and thus directs further theoretical sampling. This is known as the systematic densification and saturation of the theory (Punch, 2005).

According to Glaser (1978, 1998) an essential step that often ignored in this final stage of coding is conceptualising how the codes may relate to each other as hypotheses that explains the phenomena under investigation. In his words (1978, p. 72) thinking theoretically about the codes in this way “weave the fractured story back together”. Glaser (1998, p. 164) suggests that the grounded theorist should think theoretically when writing and coding in the final stages of analysis. To assist the researcher in this process of thinking theoretically Glaser (1998) proposes eighteen coding ‘families’ to keep in mind when coding data. In the course of coding for the study these coding families were referred to, though the analysis was not limited to them.

3.4 ***Research Ethics***

Ethics was an ever-present consideration in this study. Ethical considerations encompassed both the beneficence to and respect for persons involved in the research, as well as the quality of the research itself. As this study was conducted at the institution where the researcher was employed as an academic staff, it raised important issues regarding power relationships and associated student risk. Thus, it was necessary to seek ethical approval for the study from this institution before proceeding further. After this was carried out successfully, ethics approval was also sought and received from Monash University’s Standing Committee on Ethics in Research involving Humans (SCERH) (see Appendix D – Proof of Ethics Approval). As per the requirements of SCERH and the expectations of Monash University, all the standard procedures were put in place to ensure that ethical practices were followed. These procedures are described in the sections that follow.

3.4.1 *Consent, Access and Protection of Human Participants*

The survey was conducted online as an optional survey for all engineering students. Student participants could choose to respond to it at any time within a one-month period using a personal computer with intent access. The survey tool captured a unique alphanumeric identifier for each student for the explicit purpose of linking his or her responses with available demographic information. Once the demographic information was linked with the survey data, the unique identifiers were removed by the researcher rendering the data anonymous. As a further precaution to protect individual students from being identified, only aggregated data from the survey was reported in this thesis.

Before the in-depth interviews started, the students who had been identified as part of the study population were contacted, the reasons for approaching them outlined, the purpose of the data and the interview established, the potential benefits of the research explained and their permission to be interviewed obtained. Students received an explanatory statement and consent form containing relevant information about the study and expectations of the participants before they took part in the study (see Appendix E – Explanatory Statement and Consent Form). In the interest of maintaining confidentiality and anonymity, pseudonyms were used in reporting and presenting, and students were assured that verbal or written accounts based on the study would not allow individuals to be identified. The one-on-one interviews were conducted at a pre-arranged time at a place of the participants' choosing within the campus grounds and, with their consent the conversations were audio-recorded. Participants were assured that they could withdraw from the study at any time and should they choose to withdraw their interviews would not be analysed and the recording would be destroyed. Furthermore, all research data and notes arising from this study were kept under lock-and-key in a secure location, accessible only to the researcher.

3.4.2 *Quality Controls*

All of the quality controls employed in this study are intended to achieve two important constructs in any research, namely validity and reliability. The use of reliability and validity are well established in quantitative research and certain researchers (Golafshani, 2003; Onwuegbuzie & Leech, 2007) suggest that these constructs should be reconsidered in the qualitative research paradigm. However, since reliability and validity are rooted in the positivist perspective that is usually associated with quantitative approaches, they should be redefined for their use in qualitative approaches.

Validity refers to the extent to which the results of the study reflect the actual reality being studied. In a broad sense it encompasses credibility, precision, and freedom from researcher bias (Golafshani, 2003; Onwuegbuzie & Leech, 2007). Reliability refers to the extent to which the research is dependable and whether or not the results of the study can be reproduced under a similar methodology. It relates to the degree to which a measurement, given repeatedly, remains the same and encompasses the consistency, dependability and applicability of the research design (Golafshani, 2003; Moskal, Leydens, & Pavelich, 2002). Validity and reliability are issues that are important to both quantitative and qualitative research. Miles and Huberman (1994, pp. 277-280) compare concepts related to validity and reliability in qualitative and quantitative research approaches, concluding that these concepts were equally applicable to both research paradigms.

However, it should be noted that although reliability and validity are treated separately in quantitative research, these constructs are not regarded as separate in qualitative studies.

One of the strongest quality controls for this type of social science research is triangulation (Golafshani, 2003; Mathison, 1988). Triangulation aims to establish the validity and reliability of the data collected and interpretations arising from the data, by drawing upon multiple sources for the data and multiple methods of data collection. Mathison, (1988) identified four types of triangulation; data triangulation (from a variety of data sources), investigator triangulation (from more than one researcher), theory triangulation (using multiple perspectives in the analysis) and methodological triangulation (using multiple or mixed methods). This study employs data triangulation and methodological triangulation. Both numerical and verbal data were collected, using both a large-scale survey and individual interviews. Comparing data from two distinct sources to verify that interpretations of one source are consistent with the other, allowed for a significant degree of triangulation and a high level of confidence that the results of the study were valid and reliable.

Another important quality control, especially for the interpretation of the qualitative data, was to enhance its 'trustworthiness'; as expressed by Lincoln and Guba (1985). The following four methods were employed to ensure trustworthiness. Firstly, the researcher was acutely aware of his own biases and subjectivity when interpreting data and put in place the following system to eliminate such biases. Secondly, throughout the study, the research participants were involved in verifying the transcribed interviews and their opinion was sought on the validity of the emerging hypotheses, categories and interpretation of the data. Thirdly, data were also examined with other researchers and educators in the field to ensure no meanings were being forced onto the data. Finally, an "audit trail" in the form of this thesis was created that allows future researchers to repeat the data collection and confirm the reliability of the data. The chain of evidence was established through the detailed documentation of survey instrument used, any modifications, analytical methods, interviews, notes, transcription, coding and matrices of results for transparent comparison.

3.5 ***Summary of the Research Design and Methodology***

This chapter has described the research, the research design and the methods used which include the instruments participants, procedures and ever-present ethical considerations. The design drew on both quantitative and qualitative paradigms by using a mixed method approach. The quantitative techniques provided data that allowed a broad analysis of the learning environment and the factors associate with learning engineering, while the qualitative techniques provided data that give rich descriptions of the participants' beliefs intentions and strategies.

The survey participants and procedures were introduced. The nature of the quantitative survey instrument, along with the modifications made for the context being investigated and the statistical conventions and procedures used in the analysis, were explained. The nine students who participated in the qualitative interviews were described, as was the logic underlying the selection of these participants. The nature of the questions employed in the qualitative interviews and the reasoning behind the data analysis procedures were explained. Finally, the ethical considerations that underlie the entire research process were introduced. The ethics approval process and safeguards that protect the rights of the human participants were described. The quality controls that were built into the research design, in order to ensure validity and reliability of the research outcomes, were also highlighted.

The analysis of the quantitative data from the survey and presentation of the quantitative findings is the subject of the next chapter while that of the qualitative interview data and results provides the content of Chapter 5.

Chapter 4 Baseline Quantitative Study: Findings from an Institution Wide Survey

This chapter describes the findings of the baseline quantitative aspect of the study. It focuses on numerical data in the form of student demographic information (such as year of study and 'O' Level mathematics scores) and Likert scale responses from a modified version of the APPLES survey (Chen, Donaldson, et al., 2008). The findings in this chapter are presented in two sections. The first section presents a broad statistical analysis of the quantitative data, which allowed for the identification of important factors that influenced how engineering was learnt in the wider context of the institution. The second section of this chapter, presents a path model analysis of the relationships between these factors and helped to build an understanding of how students' mathematical backgrounds affected the process of learning engineering and the resultant engineering education outcomes. These quantitative findings helped focus the data collection and analysis in the in-depth qualitative aspect of the study that followed. The findings presented in this chapter were intended to address **Research Question 1**, which can be rewritten in two parts as follows:

Research Question 1, Part I: What are the important factors and outcomes associated with learning engineering in a dedicated Problem-Based Learning (PBL) setting?

Research Question 1, Part II: How does prior GCE 'O' Level mathematics performance affect these factors and outcome?

The findings that address these questions are presented later in this chapter, in Sections 4.2 and 4.3 respectively.

4.1 ***Representation of Quantitative Findings***

All of the responses to the survey items were captured in the form of values on either a four, or five-point scale. In order to present and compare these values meaningfully, they were normalised on a scale ranging from 0 (lowest possible) to 100 (highest possible). Values ranging from 0 to below 33.3 were classified as low; values ranging from 33.3 to below 66.6 were classified as moderate; and values ranging from 66.6 to 100 were classified as high. Normalising the values and presenting them in this way also facilitated comparison of the findings in this study with other studies that have used the APPLES instrument (Chachra, Chen, Kilgore, & Sheppard, 2009; Cohen, 1988; Parikh, Chen, Donaldson, & Sheppard, 2009).

As per convention in the social sciences (Cohen, 1992), results were reported as statistically significance if p was less than 0.05. Effect size was reported using the eta-squared (η^2) index. Eta-squares (η^2) of 0.01, 0.06 and 0.14 were by convention, reported as small, medium and large effect sizes, respectively (Cohen, 1992). When assessing the model fit of a path model, the Comparative Fit Index (CFI) of greater than 0.95 and the Root Mean Square Error of Approximation (RMSEA) of less than 0.08 were taken to be indicators of model fit (Meyers, et al., 2006). As a further indicator of the degree of fit with the data, the model also should have a low chi-square (χ^2) score relative to degrees of freedom (*df*). This is taken as between 2.0 to 5.0 in this study. The statistical conventions that have been listed here were adopted consistently throughout this study. The rationale for adopting these conventions and the statistical analysis employed were discussed in detail in Chapter 3.

4.2 ***Research Question 1 Part I: Factors Associated with Learning Engineering***

Learning engineering is a complex process that is affected by many interrelated factors. The intent of this part of the study was to identify important factors associated with learning engineering by examining how students' mathematics background and skills could affect their current experience of learning engineering. In order to do this it was first necessary to understand how engineering was learnt in the wider context of the institution, across all three years of study. To this end, findings that were generalisable to the entire cohort of engineering students in the institution are presented in the subsequent sections.

All results in this study were based on the demographic and survey responses of 1217 engineering students who took the 'O' Level prior to admission to the institution. These respondents to this survey made up over 40% of entire engineering cohort. The results were grouped into several areas of particular interest to engineering education and presented in sections 4.2.1 to 4.2.4. These areas of interest are:

- The effect of prior mathematics ability on the outcomes of engineering diploma programmes (Section 4.2.1),
- Student perceptions about learning engineering and perceptions of their own ability to learn engineering (Section 4.2.2),
- The motivation to learn engineering (Section 4.2.3),

- Student exposure to and knowledge of the engineering profession (Section 4.2.4),
- Engineering students' overall engagement in and satisfaction with the polytechnic experience (Section 4.2.4).

4.2.1 *Mathematics Performance and Engineering Education Outcomes*

This section presents results that show how prior mathematics ability directly affects the engineering education outcomes of students. The two engineering education outcomes that were considered were: (i) current academic performance; and, (ii) students' intentions to either study or work in an engineering related field after graduation. The analysis revealed that prior mathematics performance did seem to have a small correlation with current academic performance in engineering courses. However, prior mathematics scores did not seem to affect students' intentions to either study or work in an engineering related field. These two engineering education outcomes were considered distinct outcomes as they only correlated very slightly with each other.

In this study, prior mathematics performance was measured by students' GCE 'O' Level mathematics scores taken prior to enrolment into the polytechnic. The GCE 'O' Level was an entrance requirement for all of the students in this study. A grade in any GCE 'O' Level examination subject is a letter with an accompanying number. From best to worst, the grades are A1, A2, B3, B4, C5, C6, D7, E8, and F9. Grades from D7 to F9 are considered a failure in the subject. The grade of D7 is the lowest allowable mathematics grade for students enrolled in engineering diplomas. Students with this grade in mathematics were conditionally accepted into their diploma programs. For the purpose of analysis the letter grades for each student were re-coded using a 7-point scale, such that A1=7.0, A2=6.0, B3=5.0, B4=4.0, C5=3.0, C6=2.0 and D7=1.0. The average GCE 'O' Level mathematics grade for the engineering students who participated in the study was close to a grade of C5 (M = 2.9, SD = 1.64).

The intended outcomes of engineering education at the polytechnic where this study was conducted, are to equip students with engineering knowledge and skills, and to prepare them for either engineering related jobs or further studies in engineering (Alwis & O'Grady, 2002). Therefore, both current academic performance and students' intentions to persist in engineering after their diploma studies were considered important outcomes of engineering education for this study.

The measure of current academic performance used in this study was the students' Grade Point Average (GPA) in the polytechnic. The GPA is a cumulative measure of all of the subjects that students have been assessed for, up to the point where this study was conducted. Approximately 50% of every engineering student's GPA comes from a unique assessment measure called the Daily Grade. The Daily Grade is a grade awarded to a student by the facilitator of the class, on each day of attendance in a classroom activity of a module, based on the process skills displayed by the student during that day. In addition, there are three written tests conducted at different points in the semester for each module, aimed at testing the students' understanding of the subject matter. These written tests make up the remaining 50% of the GPA. The GPA has a range of 4.0 to 0.0, where 4.0 is the best possible grade and 2.0 is the minimum passing grade. The mean GPA of participants was 2.58 out of 4.0 ($SD = 0.54$). The survey variable of Professional Persistence was used as a measure of students' intentions to either work in an engineering related career or study engineering after graduation. The mean Professional Persistence score was 62.2 out of 100 ($SD = 27.8$). Interestingly these two outcome measures only correlated very weakly, Pearson's $r(1216) = 0.07$, $p = 0.02$. This indicated that factors other than student performance in their engineering studies affected student intentions to work in engineering or continue studying engineering.

GCE 'O' Level mathematics grades and current GPA were found to be positively correlated, Pearson's $r(1216) = 0.23$, $p < 0.001$. This correlation which was between 0.1 and 0.3 is considered small by convention, though finding very high correlations is rare in the social sciences (Cohen, 1988). This result indicated that while mathematics skills did affect academic performance, other factors might also have an important role to play in determining how well engineering is learnt.

Surprisingly, no significant correlation was found between GCE 'O' Level mathematics grades and students Professional Persistence scores, Pearson's $r(1216) = 0.005$, $p = 0.87$. However, analysis of variance (ANOVA) procedures revealed that mean Professional Persistence scores did decrease moderately with each year of study [$F(2, 1214) = 39.8$, $p < 0.001$, $\eta^2 = 0.06$] as illustrated in Figure 4.1. This drop in Professional Persistence as students approach graduation is an area of concern for the polytechnic, as the institution is tasked with developing future engineers and engineering technicians.

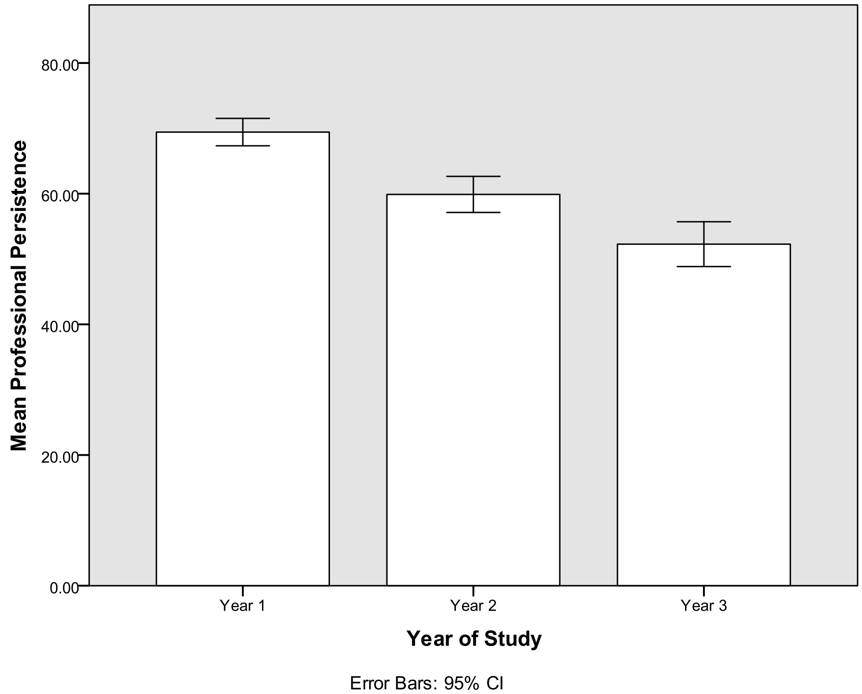


Figure 4.1 - Effect of year of study on Professional Persistence

4.2.2 *Perceptions about Learning Engineering*

This section presents findings about student perceptions of learning engineering and student perceptions of their own ability to learn engineering. The analysis revealed that students perceived mathematics and science skills as well as professional and interpersonal skills as highly important. However, their confidence in these skills was only moderate. These perceptions remained relatively unchanged throughout the three years of study.

Students perceived that mathematics and science skills (M = 82.3, SD = 19.7) as well as professional and interpersonal skills (M = 72.6, SD = 18.1) were both highly important in learning engineering. A paired-samples t-test indicated that students perceived mathematics and science skills as being more important than professional and interpersonal skills [$t(1216) = 15.7$, $p < 0.001$]. Analysis of variance (ANOVA) procedures were conducted to determine if these perceptions changed depending on the year of study. The ANOVA showed there was no effect of the students' year of study on either the perceived importance of mathematics and science skills [$F(2, 1214) = 0.74$, $p = 0.48$] or the perceived importance of professional and interpersonal skills [$F(2, 1214) = 0.06$, $p = 0.94$].

The students' confidence in their ability in mathematics and science ($M = 54.4$, $SD = 21$), professional and interpersonal skills ($M = 64.7$, $SD = 16.8$) and solving open-ended problems ($M = 61.2$, $SD = 19.3$) was moderate. ANOVA procedures were conducted to determine if students' confidence in their ability changed depending on the year of study. There was no effect of year of study on confidence in mathematics and science skills [$F(2, 1214) = 0.77$, $p = 0.47$] or on confidence in professional and interpersonal skills [$F(2, 1214) = 0.07$, $p = 0.98$]. There was a very slight effect on confidence in solving open-ended problems [$F(2, 1214) = 0.07$, $p = 0.98$, $\eta^2 = 0.006$] but this was negligible.

4.2.3 *Motivation to Learn Engineering*

This section presents an analysis of the motivational factors to learn engineering across the institution. All of the measured variables relating to students' motivation to learn engineering were either low or moderate. In general, motivation decreased as students progressed through their three years of engineering studies.

Motivational factors such as parental influence ($M = 17.9$, $SD = 25.4$) and mentor influence ($M = 25.3$, $SD = 24$) were low; while financial motivation ($M = 46.8$, $SD = 24.8$), motivation for social good (M = 55.3, SD = 25.3), intrinsic psychological motivation (M = 47.1, SD = 28.9) and intrinsic behavioural motivation (M = 53.4, SD = 30.3) were moderate. ANOVA procedures revealed that the year of study had no significant impact on parental influence [$F(2, 1214) = 1.48$, $p = 0.23$] and mentor influence [$F(2, 1214) = 2.71$, $p = 0.07$]. However, year of study did have a significant impact on financial motivation (p = 0.034, η^2 =0.006) motivation for social good ($p < 0.001$, $\eta^2 = 0.028$), intrinsic psychological motivation ($p < 0.001$, $\eta^2 = 0.044$) and intrinsic behavioural motivation ($p < 0.001$, η^2 = 0.025) as shown in Figure 4.2 on the following page.

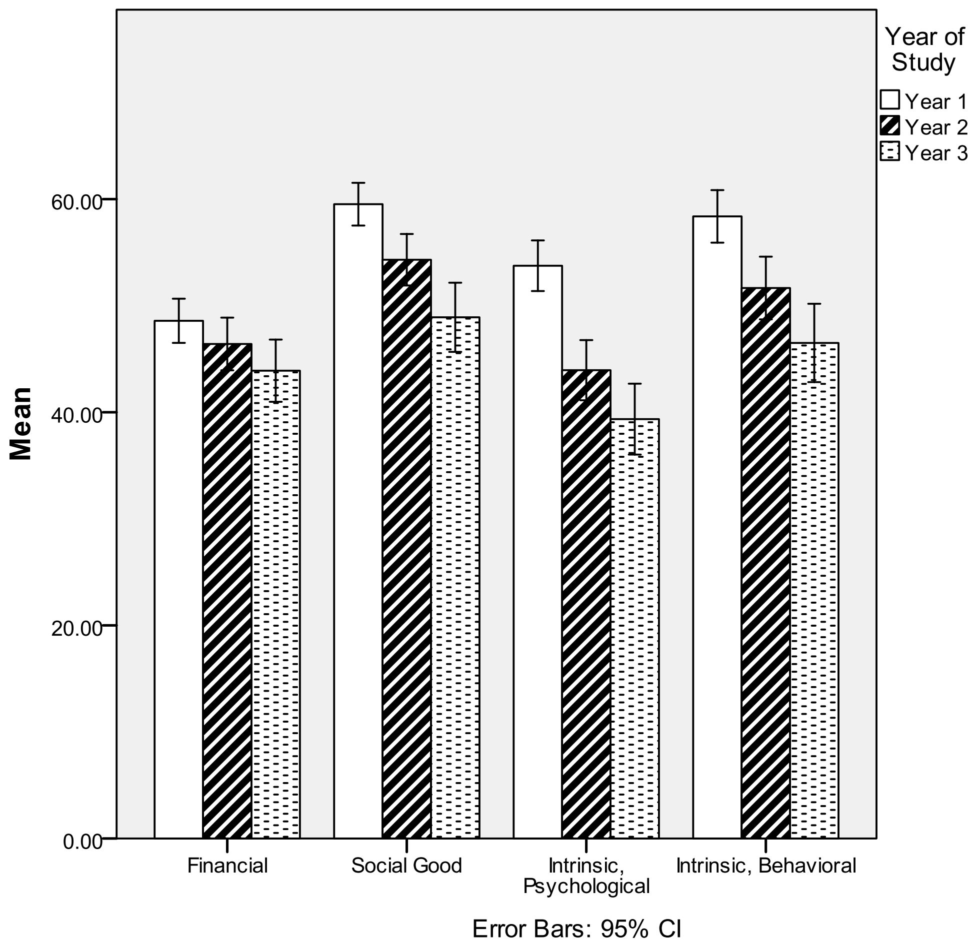


Figure 4.2 - Motivational factors that are significantly affected by year of study

Since these variables associated with motivation seem to change in tandem with year of study, it is plausible that they are associated with an underlying factor. The three variables that show the greatest change, ‘Social Good’, ‘Intrinsic Psychological’ motivation and ‘Intrinsic Behavioural’ motivation are all generally related to the psychological construct of intrinsic motivation. Further reinforcing this idea, the Cronbach’s Alpha score of these three variables was high ($\alpha = 0.87$) which indicated that they can be treated as measuring the same latent construct. Though this psychological construct of intrinsic motivation has evolved from its original usage (Ryan & Deci, 2000), and has been challenged as meaningless by some authors (Reiss, 2004), it is still a major feature in current educational research and literature.

4.2.4 *Exposure to the Engineering Profession*

This section presents an analysis of variables related to students’ knowledge of and exposure to the engineering profession. In general, students were not very involved in engineering activities outside the curriculum though they did learn more about engineering through their three years at the polytechnic.

One area of concern was that students felt that they had low exposure to the engineering profession ($M = 30.8$, $SD = 27.4$) and low involvement in engineering related activities outside class ($M = 21.2$, $SD = 27.1$). However, students rated their current knowledge of the engineering profession as moderate ($M = 54.5$, $SD = 25.9$). By comparison they felt they had moderate involvement in non-engineering extracurricular activities ($M = 55.7$, $SD = 30.8$).

ANOVA procedures were conducted to determine if year of study affected how much students were exposed to the engineering profession. There was no significant change in student involvement in engineering related activities outside class [$F(2, 1214) = 0.20$, $p = 0.82$] or involvement in non-engineering extracurricular activities [$F(2, 1214) = 0.83$, $p = 0.44$]. However, there was a moderate increase in students' exposure to the engineering profession [$F(2, 1214) = 38.7$, $p < 0.001$, $\eta^2 = 0.06$] and a large increase in students' current knowledge of the engineering profession [$F(2, 1214) = 136.3$, $p < 0.001$, $\eta^2 = 0.18$]. This indicated that as students' progress through their diploma programme they did become more prepared for the engineering profession and for further studies in engineering.

4.2.5 *Engagement with the Polytechnic Experience*

Studying engineering is often a demanding experience and studying engineering through Problem-Based Learning (PBL) may add to the demands on a student. This section presents an analysis of how engaged in, and satisfied, students were with various aspects of the polytechnic experience. The analysis revealed that students were quite satisfied with the institution and quite engaged in their studies, though disengagement increases as students' progress though their diploma.

Overall students were moderately satisfied with their polytechnic experience ($M = 57.2$, $SD = 27.4$). Students felt that the frequency of their interaction with their instructors was moderate ($M = 37.3$, $SD = 21.2$) and were moderately satisfied with the quality of their instructors ($M = 63.0$, $SD = 20.9$).

Even though students felt moderately overloaded by the curriculum (*M* = 48.5, *SD* = 17.1), they had a strong intention to complete their engineering diplomas (*M* = 91.5, *SD* = 17.1). Disengagement in both engineering related subjects (*M* = 31.7, *SD* = 20.9) and non-engineering subjects (*M* = 29.2, *SD* = 21.5) was low. This low disengagement may be because students were learning engineering through PBL.

ANOVA procedures showed that all of these factors were significantly affected by year of study, but changes in most of these factors were small to negligible ($\eta^2 < 0.01$). The two factors that were more affected were disengagement in engineering related subjects ($p < 0.001$, $\eta^2 = 0.03$) and curriculum overload ($p < 0.001$, $\eta^2 = 0.10$). The relationship of these factors to year of study is shown in Figure 4.3. The jump in disengagement in engineering subjects and curriculum overload between the first and second-year of study was likely due to the fact that students move from taking general subjects (such as general mathematics and science) to taking engineering specific subjects (such as digital electronics and circuit design). These results indicated that taking engineering related subjects did seem to increase the workload on students and made them more disengaged.

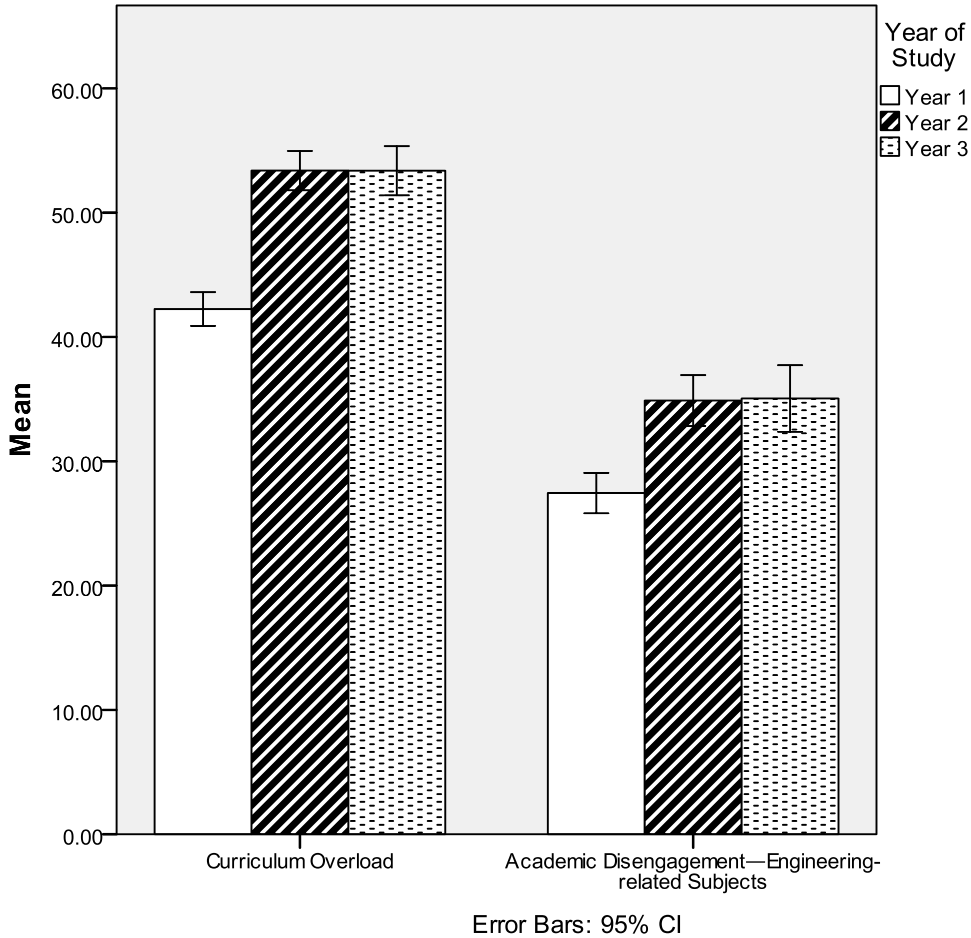


Figure 4.3 - Effect of year of study on and curriculum overload and disengagement in engineering

4.2.6 *Summary of Factors Affecting How Engineering is Learnt*

The analysis revealed one similar aspect to other studies on learning engineering (Budny, et al., 1997; LeBold, et al., 1989; Shaw & Shaw, 1997), which was that prior performance in mathematics did have some direct effect on current performance in engineering. However, the correlation between these measures was not large and other factors probably did have an important effect on the experience of learning engineering at the polytechnic.

Prior mathematics performance did not seem to have any direct influence on a student's desire to persist in engineering related fields after graduation. However, for some reason students desire to persist with engineering drops significantly, as they advance through their engineering diploma programme. Arguably, training graduates who will in turn support the engineering industry in Singapore is one of the major purposes of an engineering education at the polytechnic (Alwis & O'Grady, 2002). Therefore, the desire to persist in engineering after graduation is an important engineering education outcome that should be explored further, especially in terms of how this outcome may be indirectly affected by prior mathematics performance.

Students' perceptions about what engineering is, and their perceptions about learning engineering, likely have an influence on the choices they make in their engineering studies. The analysis revealed that students recognised the importance of both hard and soft skills associated with engineering. However, their confidence in these skills lagged behind how important they thought these skills were. These perceptions seemed to be shaped by prior experience, as they remained relatively unchanged throughout the three years of study. One reasonable hypothesis is that prior experience with engineering related subjects such as mathematics, have greater influence on shaping their perceptions than current engineering studies.

Another important issue is student motivation to study engineering. The analysis revealed that student motivation was, overall, low to moderate. Variables related to intrinsic motivators seemed to have a bigger influence on students than other motivators did.

However, there was a marked decrease in these aspects of motivation as students progressed through their three years of engineering studies. The question as to why there was such a clear drop in intrinsic motivation as students approached graduation needs to be looked at closely by the institution, especially in terms of how it may directly, and indirectly, affect engineering education outcomes.

On a more positive note, students did learn significantly more about the profession of engineering through their three years at the polytechnic. This seems primarily due to the engineering curriculum that students experience in class, as students were not very involved in engineering activities outside the classroom. Instead, students were much more involved in non-engineering extra curricula activities of their own interest. This involvement in other aspects of student life may be one of the reasons why students were quite satisfied with their experience at the polytechnic.

Students became slightly more disengaged with their studies as they moved from the first-year to the second-year of their diploma programme. This increase in disengagement seems to be connected to engineering related subjects. Despite this increase, disengagement overall was quite low when compared with other engineering contexts. This was a point of interest, as student motivation to study engineering was only low to moderate. One explanation that the literature seems to support (Smith, et al., 2005) is that students were more engaged because they were learning engineering though PBL.

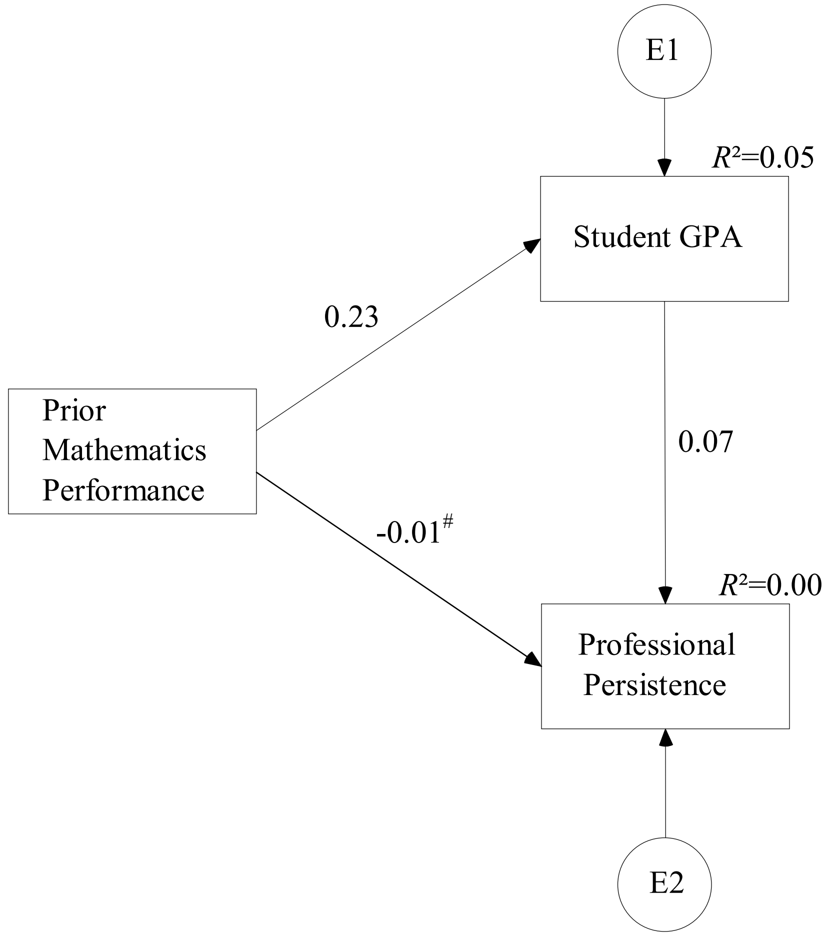
4.3 ***Research Question 1 Part II: Effects of Prior Mathematics Performance***

The cognitive and psychological factors described in the preceding sections, give a snapshot of learning engineering within the wider context of the institution. However, in order to truly understand how prior mathematics performance affects the entire process of learning engineering, one has to analyse the direct and indirect effects of these factors on each other, and identify relationships between these factors that may be causal. Path analysis has been identified as a well-established analytical technique that can achieve these goals.

The path analysis procedure was presented briefly in the Research Design and Methodology chapter (Chapter 3). Path analysis enables the statistical testing of a hypothetical model of cause and effect and produces an explicit result of the strengths of the mathematical relationship contained within the model. The models presented in this section were created using AMOS 16.0 and illustrate the causal relationships among various independent and dependent variables. As suggested by various authors (Meyers, et al., 2006; Raykov & Marcoulides, 2006) the final models were assessed by a number of statistical indices that reflect the extent to which the model can be considered an acceptable representation of the data.

4.3.1 *Selection of Dependent and Independent Variables*

In a path analysis, it is necessary to differentiate between dependent and independent variables in the data. Dependent variables are variables that can be at least partially explained by other variables in the model, while independent variables are input variables that cannot be explained within the model. In other words, dependent variables receive at least one path from another variable, while independent variables emanate paths but do not receive paths. As defined in preceding sections, two important outcomes of engineering education at the polytechnic were: (i) current academic performance as measured by 'Student GPA'; and, (ii) students' intentions to persist in engineering after their diploma studies as measured by Professional Persistence. These two outcomes were considered dependent variables. The purpose of this path analysis was to determine how prior mathematics performance affected the process of learning engineering. Therefore, 'Prior Mathematics Performance' was defined as an independent variable. The direct relationship between these variables has been previously discussed and is illustrated in the model in Figure 4.4. All dependent variables have a residual error term that is not explained by the model and is denoted by E (for Error).



#. **Not significant** at the 0.05 level (2-tailed)

Figure 4.4 - Direct relationship between prior mathematics performance and the outcomes of engineering education

The above model is not very useful, as it does not explain much of the variation in either of the outcomes. In this model prior mathematics performance directly accounts for 5% of the variation in student GPA ($R^2 = 0.05$). This was a positive indication, as it is undesirable for prior academic performance to be an extremely strong predictor of current academic performance in any educational system. A very strong predication in this case would have indicated that nothing much is being added to a student's intellectual makeup by the education he or she receives. The model also showed that prior mathematics performance and current GPA did not have a noteworthy direct effect on students' Professional Persistence. Hardly any of the variation in Professional Persistence could be explained (R^2 = 0.00) by the model. This result was especially interesting when considering the high importance most students place on mathematics and science skills (M = 82.3, SD = 19.7). It indicated that the connection between mathematics skills and the desire to persist in engineering was not as straightforward as usually assumed, and should be investigated further. Since prior mathematics performance did not directly affect students' intentions to persist in engineering, other intermediate dependent variables needed to be considered to build models that are more complete.

In order to determine the intermediate dependent variables, a Pearson bivariate correlation was conducted using these three variables and all of the other measured variables from the survey. It should be noted that correlations by themselves do not establish if any of these variables effect, or are affected, by other variables. However, correlations between distinct variables indicate a possible causal relationship that can be verified by conducting a path model analysis. An inspection of the inter-correlations of variables from the survey revealed three additional variables of interest that could be added to the model. These were 'Intrinsic Motivation', 'Confidence in Mathematics and Science Skills' and 'Academic Disengagement (Engineering-related Subjects)'. A second reason for the selection of these variables was that they seemed to be important factors connected to learning engineering at the polytechnic as previously discussed in Section 4.2.6 'Summary of Factors Affecting

How Engineering is Learnt'. Table 4.1 displays the inter-correlation matrix for all of the selected variables used in the subsequent path modelling.

Table 4.1

Inter-correlation matrix of the variables used in path modelling

	Student GPA	Professional Persistence	Intrinsic Motivation	Confidence in Mathematics and Science Skills	Academic Disengagement (Engineering Subjects)
Prior Mathematics Performance	**0.231****	0.005	0.022	**0.398****	0.027
Student GPA	-	**0.068***	**0.072***	**0.202****	**-0.381****
Professional Persistence		-	**0.540****	**0.288****	**-0.176****
Intrinsic Motivation			-	**0.425****	**-0.127****
Confidence in Mathematics and Science Skills				-	-0.095**

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

4.3.2 *Modelling Effects of Prior Mathematics Performance on Learning Engineering*

A path model was created using AMOS 16.0 to determine the relationship between: (i) the independent variable of 'Prior Mathematics Performance'; (ii) the variables of interest selected from the survey; and, (iii) the variables measuring engineering education outcomes. Directional arrows were used to indicate the hypothesised causal or direct relationship. The initial model postulated many causal relationships between the various variables. This model was iteratively modified by removing arrows that indicated weak connections between variables. This was done in the interest of achieving a parsimonious final model. The final model was assessed by the acceptable model fit indices as described in the Research Design and Methodology chapter. This model is shown in Figure 4.5.

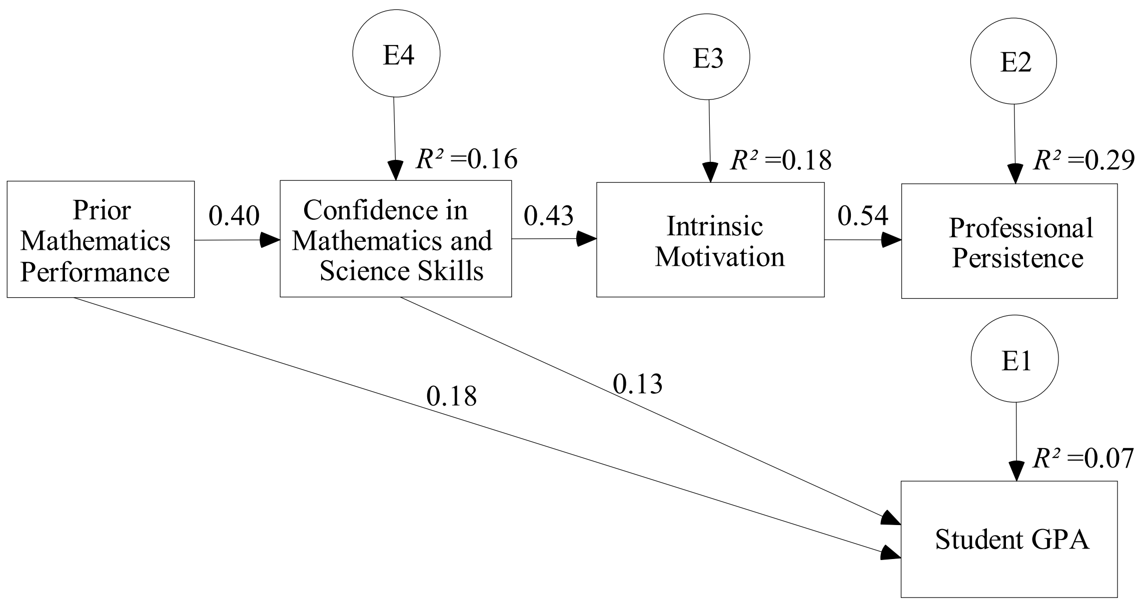


Figure 4.5 - Path model of the effect of prior mathematics performance on engineering education outcomes

This model has only one exogenous independent variable, 'Prior Mathematics Performance'. The model accounted for 29% of the variance in students' 'Professional Persistence', but only 7% of the variance in students' GPA. The model had a CFI of 0.96 and a RMSEA of 0.08. The χ^2/df ratio was 2.71.These model fit indices indicated a relatively good fit between the model and the empirical data, therefore this model was accepted.

This model illustrated the importance of confidence in mathematics and intrinsic motivation in addition to prior mathematics performance in affecting educational outcomes. Of interest is the large positive affect ($\beta = 0.49$) of confidence in mathematics and science skills on intrinsic motivation. The model clearly shows the indirect effect from mathematics performance on students' intentions to work or study engineering after graduation. While this is an important finding, it does not explain exactly how poor mathematics performance leads to lower confidence, how lower confidence leads to less intrinsic motivation or how less intrinsic motivation leads to lower Professional Persistence. It only shows that such a connection does exist.

4.3.3 *Factors Affecting Student GPA*

The earlier model did not explain much of the variation in student GPA. In order to explain more of the variation in student GPA a second model was constructed to account for the effect of other variables that were not in the first model. Variables that did not have a significant effect on GPA were removed and other variables from the survey were tested to try to improve explanatory power of the model on GPA. The model was iteratively modified to achieve parsimony and assessed by the acceptable model fit indices as in the previous model. The final model, showed in Figure 4.6, involved the addition of a single additional independent variable that was not in any of the previous models, Academic Disengagement (Engineering Subjects).

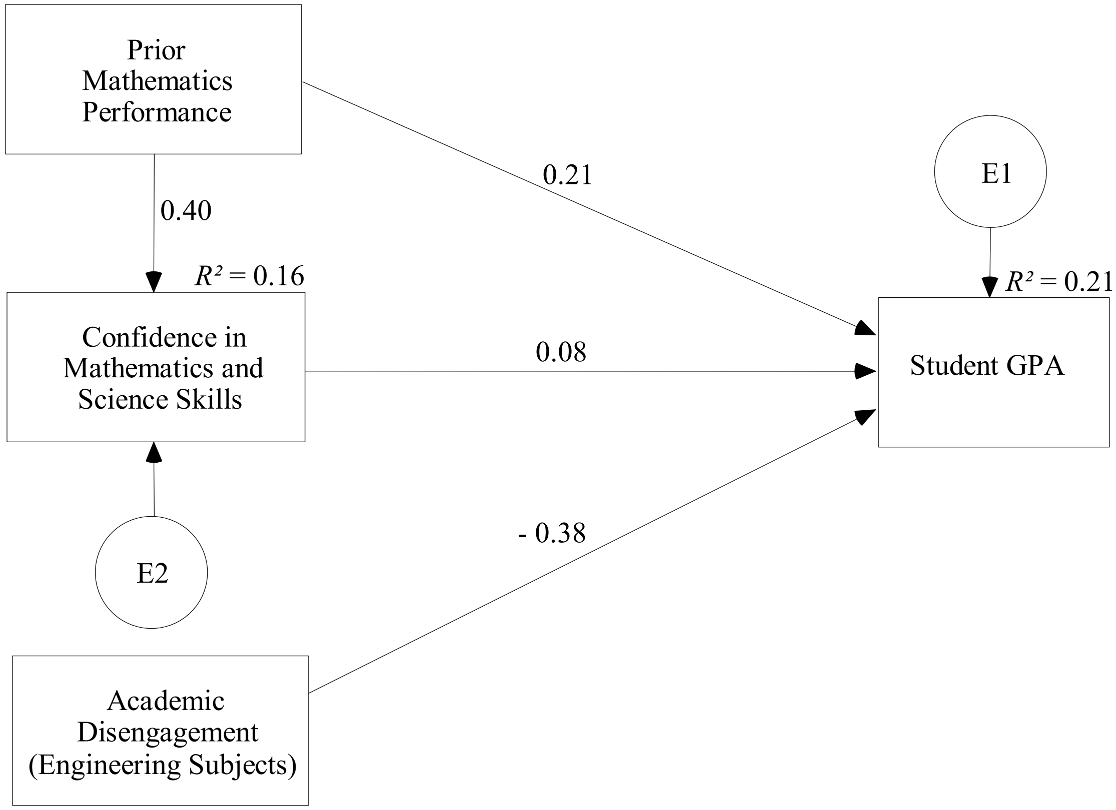


Figure 4.6 - Model of the variables affecting student GPA

This model accounted for 21% of the variance in a student's GPA. Academic Disengagement (Engineering Subjects) was considered an independent variable as other measured variables in the survey could not account for much of its variation. It was therefore concluded that it was an exogenous independent variable affected by factors outside the model. The model had a CFI of 0.97 and a RMSEA of 0.079. The χ^2/df ratio was 8.57. These model fit indices indicated a moderate fit between the model and the empirical data and therefore this model was accepted.

These results indicated that prior mathematics performance alone was not a major determinant of current academic performance or, by inference, engineering skills acquired at the end of a diploma programme. Academic disengagement in engineering subjects seems to have a central role in this area. When further analysis was done to explain the causes of academic disengagement in engineering subjects, it was found that this factor was not greatly affected by prior mathematics performance or other survey variable such as, confidence in mathematics and science skills and intrinsic motivation. It is possible that there exist a connection between mathematics ability and academic disengagement, which was not captured by the quantitative survey data. Speaking to students and collecting qualitative data from them has the potential to shed light on this issue and better explain what causes some students to be disengaged with engineering subjects.

4.4 ***Summary of Findings of the Institution Wide Survey***

The analysis of factors associated with learning engineering in the wider context of the institution revealed a number of trends across the three years of study. The intention to persist in engineering studies or work after graduation decreased significantly, as students approached graduation. Students' perceptions about learning engineering did not seem to change across the three years, indicating that these perceptions were possibly shaped by experiences prior to their enrolment at the polytechnic. Motivation, in particular intrinsic motivation decreased significantly across the three years. Students were not very involved in engineering related activities outside the classroom but they did learn significantly more about the profession of engineering through the engineering curriculum. Students became slightly more disengaged with their studies as they started to do more engineering related subjects in the second and third-year of their diploma programme.

The results from path model analyses supported the theory that prior mathematics performance affects the process of learning engineering as well as engineering outcomes. Confidence in mathematics and science skills and intrinsic motivation to study engineering also seemed to be important factors that are connected to prior mathematics performance. All of these factors either directly or indirectly affected students' current performance in engineering and students' intentions to become engineers in the future. Current performance in engineering was also largely affected by disengagement in engineering related subjects. However, the reasons for this disengagement in engineering related subjects could not be adequately explained by any of the other measured variables. The path models generated show the real impact of prior mathematics performance on learning and outcomes in the institution at large. However, these models do not explain why individual students are affected by poor prior mathematics performance or more importantly, how some overcome this hurdle and succeed in the engineering programmes. The accounts from individual students in the in-depth qualitative study added another dimension to this study, triangulating the quantitative findings and offered further insights into some of these questions.

Chapter 5 In-Depth Qualitative Study: Findings from the Student Interviews

The current chapter presents the results from a series of semi-structured interviews conducted with nine engineering students, who failed 'O' Level mathematics prior to admission into a polytechnic. All nine interviewees were second and third-year students, who had completed at least three whole semesters of their respective engineering diploma programmes. This qualitative investigation allowed insights into the ways that these students approach their engineering studies, given their previous poor performance in mathematics. The use of qualitative methods provided a means of describing how engineering students think about the mathematics that they encounter, and how this consequently affected their intentions and strategies for learning engineering. Qualitative methods also made it possible to explain the process by which these beliefs and strategies were formed. Finally, it also allowed for an exploration of the effect of these student beliefs and strategies on important qualitative outcomes of engineering education, which are not always evident in standard educational measures such as test scores. The main aim of this chapter is to address Research Questions 2, 3 and 4, as reiterated below:

Research Question 2: What do students, who have previously failed the GCE 'O' Level mathematics, believe about the mathematics they have learnt; and how do they approach mathematics in the context of engineering education?

Research Question 3: What are these students' beliefs about engineering knowledge; how do they approach engineering problems in a dedicated PBL setting; and what are their expectations of the engineering profession?

Research Question 4: What is the grounded explanation for these students' experience of learning engineering; and how does this experience affect the educational processes and outcomes of these students?

This chapter focuses on only the findings and insights gained from the analysis of the participants' interviews. The study methodology, including the procedures used, data collection strategy, description of the student participants and data analysis methods employed, were presented in a previous chapter, Chapter 3. The findings from both this in-depth qualitative study and the baseline quantitative study of the wider engineering student population offered insights into why students adopt certain beliefs and approaches. The qualitative findings in particular, revealed in what ways these beliefs and approaches affected how students learnt engineering. In response to the main research problem of this thesis, a thematic analysis was conducted integrating both the quantitative findings presented in Chapter 4 and qualitative findings presented in this chapter. This thematic analysis of all the findings resulted in a theoretical model, which is presented in Chapter 6.

The findings in this chapter are in the form of an analysis of the participants' perspective of what matters most in dealing with learning engineering in a dedicated PBL setting. While other stakeholders may hold different opinions as to what is important in learning engineering, in this type of research it is sacrosanct that the voice of the participants be given priority (Glaser & Holton, 2004). In the following section the core category, that other categories connect to and represents the main theme underpinning the study, is presented and explained. The findings that address Research Questions 2, 3 and 4 are presented in Section 5.2, Section 5.3 and Section 5.4 respectively. The relevance of each of these findings and their connection to the literature is discussed within the body of each of these sections.

5.1 ***Core Category***

In this section, the core category is described and the relationships between the core category and other participant-generated categories are summarised with a diagram. Finding the core category is an integral part of the grounded theory methodology (Glaser & Strauss, 1967). The core category can be thought of as a succinct and abstract idea that describes the broader phenomenon observed in a study. It is meant to be an idea that connects to most, if not all, of the other categories in the data. The core category that was found to underpin the various student experiences in this study was the students' 'Conceptualisation of Various Subject Domains'. This category, which emerged from the transcribed interviews through selective coding of the data, refers to how students conceptualise their learning in regards to any particular subject matter or subject domain that they encounter. It concerns the general thinking and reasoning processes of how that particular subject knowledge is acquired (Hofer & Pintrich, 1997). This is an idea that is somewhat connected to research on students' epistemological beliefs, which focuses on what students think is the fundamental nature of knowledge (Schommer, 1990). However, the idea behind the core category, as put forth in this research, is broader than just epistemology alone. It includes the perspectives, intentions and strategies of students towards coping with various subjects. These perspectives, intentions and strategies are certainly influenced by, but are not the same as students' epistemological beliefs.

An indisputable meta-goal of education is for students to develop more sophisticated perspectives of the nature of knowledge. Studies on students' epistemological development have been established in educational research for over 40 years and draw upon well-developed models such as Perry's scheme of intellectual and ethical development (1970) and the epistemological development framework proposed by Schommer (1990). Research on engineering epistemologies has been identified as one of five priority areas for research in engineering education (Steering Committee of the National Engineering Education Research Colloquies, 2006), but thus far there have only been a few studies that have utilised these models to study the specific epistemological beliefs of engineering students. For example, Marra et al. (2000) found that a change in engineering curriculum could affect the epistemological beliefs of students over a period of four years regardless of their background characteristics. King and Magun-Jackson (2009) found that educational levels and background characteristics of engineering students strongly predicted students' current epistemological beliefs regarding engineering knowledge. Ohland, Swan, and Carberry (2010) in a pilot study assessing first-year engineering students' epistemological beliefs, concluded that in general these students' epistemological beliefs could be considered “slightly sophisticated”, meaning that their beliefs fell in the higher end of Perry’s and Schommer’s frameworks.

While studies of student epistemological beliefs usually draw upon established frameworks, the same is not true for the studies concerning students’ broader conceptions of learning in various subjects. The seminal work of this kind was done by Säljö (1979) where he asked participants of different ages and from a range of educational backgrounds the question “What do you actually mean by learning?” This has led to a broad branch of research dedicated to formulating a better understanding of how students conceptualise and go about learning in different fields (Crawford, Gordon, Nicholas, & Prosser, 1994; Eklund-Myrskog, 1998; Lederman, 1992; Lin & Tsai, 2008; Marshall, Summer, & Woolnough, 1999). These studies, predominantly framed by a phenomenographic perspective, have shown that students come to different learning situations with very different preconceived views of what is meant by learning and knowledge. For example, Eklund-Myrskog (1998) showed that nursing students view learning as ‘understanding’ while automobile mechanics view learning as ‘applying’. Furthermore, Tsai (2004) showed that science students view learning science as ‘applying’ and ‘understanding’, while arts students view science as ‘calculating and practicing’. Lin and Tsai (2009) showed that engineering students with a preference for a classroom setting view learning engineering as ‘testing’ as well as ‘calculating and practicing’, whereas students who preferred a laboratory setting view learning engineering as ‘increasing one's knowledge’, ‘applying’, ‘understanding’, and ‘seeing in a new way’. Consequently, it can be concluded that how students’ conceptualise and go about learning relates to not only their academic majors (e.g., engineering, nursing or law), but also to specific subjects they encounter (e.g., mathematics, physics or history) and the learning context. All of these three influences come into play in this research project. The participants of this study were (1) all engineering majors, who (2) had to cope with different subjects in their diploma programmes, in particular mathematics, while (3) being immersed in an intensely student-centred classroom setting.

The participants' accounts of their own approaches to dealing with their engineering diplomas were the basis for the raw data in this study. Consistent with grounded theory methods, as described in detail in Chapter 3, the raw data were first open coded by means of NVIVO labels that adopted the language of the participants from verified interview transcripts. Following this, the analysis progressed to axial coding that attempted to identify a range of categories and their properties across relevant dimensions. Finally, the raw data as well as the open and axial codes, were selectively coded towards a core category that abstractly illustrated the broader social phenomenon that was the focus of this study. Selectively coding meant that coding had to be delimitated to only those themes and codes that related to the core category in significant ways. This resulted in a number of themes being excluded from the findings in this chapter. These themes have been cited for the purposes of future research in Appendix G – Excluded Themes that Do Not Relate to the Core Category.

In this study, the core category 'Conceptualisation of Various Subject Domains' is strongly linked to two distinct secondary categories, 'Conception of Mathematics' and 'Conception of Engineering'. Both of these categories were assembled from codes that relate to five themes, which emerged from the initial open and axial coding of the data. Each of these themes addresses one of two research questions (Research Questions 2 and 3) identified at the start of this chapter. These themes are:

I **Beliefs about Mathematics:** student beliefs about the nature of the mathematics they have learnt and use in their engineering studies (Research Question 2);

II **Approaches to Learning Mathematics:** student approaches to dealing with the mathematics they encountered in their engineering studies (Research Questions 2);

III **Beliefs about Engineering Knowledge:** student beliefs about which learning accomplishments counts as gaining engineering knowledge (Research Questions 3);

IV **Approaches to Solving Engineering Problems:** student approaches to solving engineering problems in the context of PBL in order to acquire engineering knowledge (Research Questions 3); and,

V **Expectations of the Engineering Profession:** student expectations of engineering profession and the engineering opportunities that await them after graduation (Research Questions 3).

This relationship between the core category, secondary categories and the five themes that emerged from the data is illustrated by Figure 5.1.

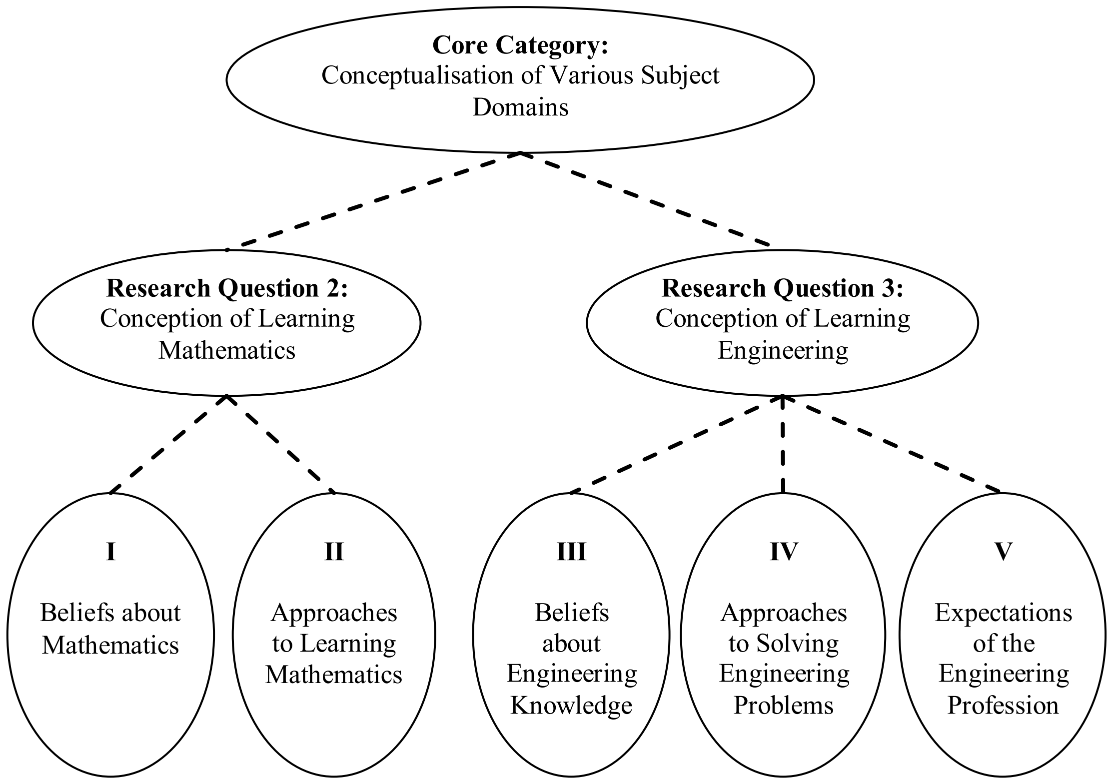


Figure 5.1 - The core category and its relationship to other categories in the data

The next section, Section 5.2, explains and summarises the two themes (I and II) that are associated with 'Conception of Mathematics'. In doing so, it will address Research Question 2, which is concerned with students beliefs about mathematics and their strategies for dealing with the heavy mathematics component of their engineering studies. Section 5.3, deals with the three themes (III, IV and V) associated with 'Conception of Engineering'. The findings presented in this section will address Research Question 3. As established in the literature review in Chapter 2, and as reflected in the themes that emerged from the data, there is an intrinsic connection between engineering and mathematics conceptions. Section 5.4 will further explore this connection by showing the relationship between these five themes. In doing so, it will partially address Research Question 4.

5.2 ***Research Question 2: Conception of Mathematics***

Seminal work in identifying and understanding the influence of students' conceptions of mathematics was carried out by Crawford et al. (1994; 1998a; 1998b), who studied undergraduate students in an Australian context. The main emphasis of these studies was the influence of students' beliefs about mathematics on their approaches to learning mathematics. The studies found that the belief that 'mathematics was a fragmented body of knowledge' was dominant among students, and that students who had this belief generally adopted a surface approach to their studies. Students whose beliefs about mathematics were more cohesive were found to generally adopt a deep approach to their studies and as a result performed better. Since then, other studies have reinforced this view and added to an understanding of this field. For example, Durrani and Tariq (2010) in a recent study of 174 undergraduates from four different faculties at a UK university found that there was a positive association between cohesive conceptions of mathematics, deep approaches to the learning of mathematics and the development of numeracy skills. Macbean (2004) focused on researching the link between the level of conceptions of mathematics and the depth of learning approaches. One additional perspective of mathematics that Macbean's study identified was the view of 'mathematics as a model to investigate matters in the world'. Houston et al. (2010) built on these previously developed phenomenographic frameworks in a recent international study involving 1200 undergraduate students of mathematics in Australia, the UK, Canada, South Africa, and Brunei. They found that the perspective of mathematics as a 'focus on models' was predominant even in an international context. In a small number of students, they identified a broader perspective of mathematics, labelled

'Life', which was a view of mathematics as a "way of thinking about reality and as an integral part of life" (p. 69).

Consulting the literature was essential in trying to make sense of the students' conceptions of learning in this study, a posteriori. However, none of the studies encountered in the literature specifically investigated the conceptions of mathematics of students studying engineering in a PBL context, as is the focus of this study. This study has the added confounders of prior mathematics failure and a predominantly Asian context, which make it inappropriate to start with an a priori generalisation for any of the other studies in the literature. This lends further credence to the grounded theory approach used in this study to identify student conceptions. The two secondary categories that link to 'Conception of Mathematics', (I) 'Beliefs about Mathematics' and (II) 'Approaches to Learning Mathematics' are presented in the next two sections respectively.

5.2.1 *Beliefs about Mathematics*

This section, describes the various codes that make up the participants' diverse beliefs about the nature of the mathematics that they have learnt and used in their studies. At the end of this section, Table 5.1 summarises the various beliefs about mathematics held by the nine participants. The issue of "what mathematics is" came up multiple times in the course of the conversations with participants. Often the participants themselves raised the issue without being explicitly probed by the interviewer. They gave a wide variety of responses regarding this issue that were summarised into five different codes. The first three codes correspond to three qualitatively different beliefs about mathematics, namely that mathematics is: (A)'Formulaic'; (B)'A Tool'; and, (C)'A Form of Thinking'. The last two codes indicate if participants believed that the mathematics they learnt was (D)'Useful' or (E)'Not Useful' to them in their engineering studies. Each code is exemplified with quotes from the participants.

A. Formulaic

The first code represents the belief that mathematics is 'Formulaic'. In this conception, students consider mathematics to be a series of steps or formula to be memorised and applied. Some participants also viewed mathematics as a collection of unrelated techniques that they have to learn. All of the participants who expressed these beliefs were quite clear that mathematics was more than just simple numbers and basic elementary arithmetic.

For example, John said that mathematics he knew was strongly associated with knowing how to apply the mathematical formulations of physics laws.

> *(The maths) I learnt about all the laws - Kirchhoff's Voltage law, Ohm's law. Besides applying all these laws, we just did division, addition, subtraction. Then a bit further down would be multiplication. (Pause) Just formulae.*

Rachel, who seemed to think that mathematics itself was formulaic but was slightly more flexible when applied to engineering, also expressed this view.

> *Because math you can't change much. Formulae are formulae. When it comes to math right? This formula is this formula. It's like one plus one is two. But when it comes to engineering you can still play with it.*

B. <u>A Tool</u>

This code represents the conception that mathematics as a whole is a toolbox, to be dipped into when necessary to solve a problem. In most cases where this belief was expressed, strong connections were also made to some real world application of mathematics.

Cai strongly expressed this view throughout his interview.

> *Because before, when the curiosity drives you and then, maybe (my engineering studies) provided me with some sort of extra thinking and because now when I'm curious I will try to use every single tool including math to try to understand the problem. Maybe when I'm just looking at a random situation at a certain place I will just maybe put in my journal what if I add more weight here or something can I balance, or more or less what it is.*

John felt that mathematics was formulaic, but he also recognised that it was a tool to be used in solving engineering problems.

> *You are actually applying math into engineering. It's a tool to understand engineering. Ya I think so…Of course first to know the purpose about why I am learning this thing. Then I can go to the math part. At the end of the day, (electronics) engineering is about making filters. So in order to design a filter, band pass filter, low band filter, I have to know the math behind.*

C. A Form of Thinking

The emphasis here is on mathematics as a logical system of thought that is somewhat abstract. Participants who expressed this belief may not necessarily have related mathematics to any real world application, but held that it was an integral part of their lives nevertheless. This rather high-level conception was expressed only two participants.

Lan's statements embody this perspective.

> *Actually, math is a complex world. You know a world where everything is numbers, formulae and I would say white hair all year you keep on thinking and thinking. If you don't love math, that's it. ... It makes me more analytical, you know, analyse things properly and I can control my stress better, I think.*

D. Useful

This code 'Useful' and the next one 'Not Useful' were not so much beliefs about mathematics, but judgements on the part of students about the utility of mathematics they learnt during and prior to their engineering studies. These codes were included here as all of the participants expressed strong and polarised opinions on whether mathematics was useful or not useful for their engineering studies. Often the belief of how useful or not mathematics was, was clearly connected to the participants' beliefs about the nature of mathematics.

For example, Fizal who believed that mathematics was both 'Formulaic' and 'A Tool' felt it was useful.

Ya it does (become useful), because at times the modules are linked together like digital wiring, circuit analysis. We use some of the similar approach like logic gates and stuff. So it has helped me like if we really prepared ourselves for learning the basic or we won't be able to do the others further up. Like other modules that are related to it.

E. Not Useful

This theme embodies the perspective that mathematics is not useful, or at least not worth the effort it took to learn.

Vick for example felt that the mathematics he had learnt was only marginally useful, despite giving the impression during his interviews that he was quite engaged with his engineering studies.

I would say that if now somebody were to tell me you need math? Math is very important for engineering? I will tell him…nonsense. I feel that what we learn in secondary school we only take like 15%, 20% and then you use it you apply in polytechnic. So the remaining 80% ya it's not I won't say useless. Not relevant…Not totally relevant.

Andi too thought that mathematics was not useful when compared to the engineering he had learnt. Part of the reason he did not find mathematics useful was that he saw it as only 'Formulaic' and nothing more.

To me engineering and mathematics are a bit different. Engineering, there's a practical way in it whereas mathematics is 100% theory. There's not any practical things you need to do with mathematics. You just need to calculate, calculate and calculate.

The participants who contributed to each these codes are shown in Table 5.1. A checkmark (✓) in this table indicates that the participant's response included at least one mention of a particular belief about the mathematics they have learnt.

Table 5.1
Beliefs about what mathematics is
Students believe the mathematics they have learnt is …

	Formulaic	A Tool	A Form of Thinking	Not Useful	Useful
Vick	✓			✓	
Tamir	✓			✓	
Fizal	✓	✓			✓
Andi	✓			✓	
Rachel	✓	✓			✓
John	✓	✓	✓		✓
Lan	✓	✓	✓		✓
Cai		✓			✓
Diana	✓			✓	

These five codes give an idea of the diverse beliefs about mathematics held by engineering students. It is obvious from participants' own words, that beliefs about what mathematics is affected their beliefs about how useful mathematics was in an engineering context. The common belief among all but one of the participants was that mathematics was 'Formulaic'. Cai, the only participant who did not express this belief, was in retrospect the most academically confident student in the group. Among the participants, it was more apparent with him than others, that he had a strong belief that mathematics was only 'A Tool'. It was however also telling that only participants who considered mathematics as 'A Tool' found it to be 'Useful' in their engineering studies. Predictably, many of the student quotes indicated that they appreciated mathematics when it was directly related to an application. The participants who expressed that mathematics was 'Not Useful' were those who believed that mathematics was just 'Formulaic' and nothing else.

5.2.2 *Approaches to Learning Mathematics*

It has already been established by a number of authors (Crawford, et al., 1998b; Schoenfeld, 1992) that an individual's beliefs about and feelings towards mathematics, influences how that individual approaches and uses mathematics. In the previous section, participants' diverse beliefs about the nature of the mathematics that they had learnt and used in their studies were presented. This section is concerned with various approaches the participants had to dealing with mathematics in the context of their engineering studies. Other similar studies (Crawford, et al., 1994; Crawford, et al., 1998a; Prosser & Millar, 1989) have used the 'deep' and 'surface' classification to categorise approaches towards mathematics. This a priori classification was not particularly useful in this study. Instead, participants' own characterisation of their approaches formed the basis of the five descriptive codes, as consistent with the grounded theory methodology adopted in this study. These codes are: (A)'Listen and Remember'; (B)'Practice by Themselves; (C)'Ask Knowledgeable Peers'; (D)'Analyse Worked Examples'; and, (E)'Just Apply the Formula'. Towards the end of this section, Table 5.2 summarises the various approaches adopted by each of the nine participants to deal with mathematics.

A. Listen and Remember

One of main rationales for adopting PBL as an instructional strategy, is to deemphasise the reliance on didactic teaching as compared with conventional instructional strategies (Barrows & Tamblyn, 1980; Coles, 1985). However, some students may still expect didactic teaching as a learner, resulting in a possible mismatch between the teaching strategy and learning approach. The descriptive code 'Listen and Remember' reflects such a learning approach, where the learner's strategy is to passively pay attention to the teacher or instructor and remember as much as possible.

A number of the participants said that this was one of their main learning approaches in regards to mathematics, despite being immersed in what was intended to be an active learning context. Andi was one such participant. He felt that for mathematics, listening to the facilitator and remembering what was said was the best way to deal with his weakness in the subject.

> *The strategy is to come to class early and just listen to the Facilitator. Because usually when they ask us to open the problem statement they will briefly explain (the mathematics), what we are going to do today, what is the*

problem like, and from there I will just understand and remember I need to do this, I need to do that.

Tamir too felt that remembering the important mathematics formula was the most important approach to dealing with the mathematics he encountered in his engineering studies. His statements however do indicate that this approach of just trying to memorise, did not always work for him.

Remembering because if I cannot remember I cannot apply. So remembering is the most important. Cos it's like too many and then sometimes the formulae can be used for different problems and sometimes for each question you have multiple formulas. So sometimes, I don't know which to use for which.

B. Practice by Themselves

Interviewer: *So, what is your approach to deal with all the Maths in your course?*

Vick: *Practice. Practice, practice, practice!*

Vick was not the only participant whose strategy was to practice solving mathematics sums until he got better, but he certainly had the most emphatic response that contributed to this code. Finding this approach to learning mathematics among the participants is no surprise. Solving mathematics problems individually still characterises much of the approaches to mathematics in secondary and primary education in Singapore, though a spectrum of other approaches are gaining a foothold as well (Foong, 2004).

Most of the participants who used this approach used it in conjunction with other approaches. Diana is the sole exception, for her, practicing was the only strategy that she mentioned in her interviews. Perhaps she was able to get by with this strategy alone because her diploma programme was less demanding in terms of mathematics than the other diploma programmes.

> *Practice, understanding. Basically, I think mathematics is more of practice. If you don't understand it you try to understand, ask for help and then you just got to do it over and over again. Do more new problems and then probably you'll get the hang of it. It's more of like getting the hang of it.*

C. Ask Knowledgeable Peers

PBL leverages heavily on peer learning and teaching and much has been written about the benefits of this approach to enhance mathematics, science and engineering learning (Hiebert, 1997; Springer, Stanne, & Donovan, 1999). It is therefore not surprising that some participants in this study depended on their peers to overcome any deficiency they personally had in mathematics; in particular peers who were perceived to be more knowledgeable in mathematics than they were. While participants' statements indicated that they were involved in more peer learning than peer teaching, they seemed to take a more active role with their peers than they did with their teachers.

Lan's statements embody this code and show that this approach of asking knowledgeable peers was the most important approach of all for him.

> *What I do is I always look through the 6Ps (hand-outs). Then I do the worksheet. The worksheet, someone helps, but the most important thing I always do is I talk to my friends who are good in math then we have like a gathering, we sit down at the library, then we just talk to each other and he helped me in certain things I helped him in certain things. Especially because he is good in math you see.*

D. Analyse Worked Examples

Worked examples can be thought of as instructional devices that provide an expert's solution for a learner to study. There is a rich body of literature which advocates for this approach to learning especially for the early stages of skill development (Atkinson, Derry, Renkl, & Wortham, 2000). The code presented here reflects using the worked example approach for mathematics only, though a number of participants also used a similar approach to solve engineering problems as discussed in a latter section (Section 5.3.2). One of the gripes of a number of the participants was that there were not enough worked examples of mathematics provided to them, and they had to seek their own expert solutions from the internet and their peers.

Rachel exemplified this in her statements:

> *I would say that Math cannot be learnt through internet. When it comes to internet it's like more on words. They don't teach you much because there are very few websites teaching you the full method step by step ... So when it*

> *comes to applying there will be certain methods you don't need to use. Like you need to use method 1 but there's no need to use method 2.*

She went on to clarify that she also looked for worked examples in books and as a last resort she asked her facilitator for a demonstration.

Lan's strategy for dealing with mathematics was also to seek worked examples, and he had a similar complaint.

> *One thing for sure is that in this Polytechnic there are not much past year paper examples, and we have to find our own self, and it's very hard for us to every time go library. And the books right, all like industrial kind of thing and the Mathematics so advanced for us. So it's very hard for me especially when I came from ITE (Institute of Technical Education) where I am used a lot of examples and suddenly I go to this Poly and it's problem-based learning.*

E. <u>Just Apply the Right Formula</u>

The approach of knowing when to appropriately apply a formula to solve a problem, was another strategy that participants adopted for both mathematics and engineering. The code 'Just Apply the Right Formula' described in this section refers to the application of this approach to mathematics only. Examples of this approach being applied solve to engineering problems is discussed in Section 5.3.2. The participants who adopted this approach were not concerned with understating how or why a formula was appropriate.

Rather, their intention was to solve the problem as simply as possible by applying the right "plug-and-play" tool.

A number of the participants claimed to have adopted this strategic approach to dealing with mathematics. One of them was John who described his approach as:

> *First discover the formulae then learn how to apply. Because honestly the lesson focus will not want us to go and explore, hey why this formula. How this formula explains the behaviour of this thing. All that. But it's rather can you know this formula. Ok you know this. You know this figure. There's such thing as so exists as this thing. Then just apply. I look at the plan, and then work out some of the numbers. Then just apply to the design.*

Vick also advocated a similar approach to dealing with mathematics. For him the focus was applying the formula correctly not understanding.

> *You go through the website, and you look for the formulas. You don't try to understand the formulas, just see the type of formulas they use. Then you apply those formulas and that aspect ya. But how it comes about previous to that formula, then I'm not sure. Like using of the formulas is my biggest strength.*

The participants who adopted each these five qualitatively different ways of dealing with mathematics are shown in Table 5.2, following.

Table 5.2

Approaches to learning the mathematics

The students' approach to learning mathematics they encounter in engineering is to…

	Listen and Remember	Practice by Themselves	Ask Knowledgeable Peers	Analyse Worked Examples	Just Apply Right the Formula
Vick	✓	✓		✓	✓
Tamir	✓				
Fizal		✓	✓		✓
Andi	✓		✓		
Rachel				✓	
John					✓
Lan			✓	✓	
Cai		✓			✓
Diana		✓			

Most of the participants adopted multiple strategies to overcome the mathematics challenges that they encountered in their engineering studies. Students, who only had one approach like Tamir and Diana, may have become demotivated if their approach did not work for them and they failed to adopt new approaches. Given the constructivist underpinnings of PBL (Savery & Duffy, 1996) it is often assumed that students ought to abandon passive approaches to learning, such as listening to the teacher and memorising, and move to more active approaches, such as peer learning and knowledge application. However, given the diverse educational experiences and abilities of students, it is likely that many may continue to be stuck in approaches that may not be suitable for the educational context in which they found themselves. Others may adopt strategic approaches like applying the right formula without understanding. Though this are not usually thought of as a ‘deep’ learning approach, it may be the best that can be expected given the students’ abilities and the educational context.

5.3 ***Research Question 3: Conception of Engineering***

As previously mentioned, a 2006 report (Steering Committee of the National Engineering Education Research Colloquies, 2006) by the Steering Committee of the National Engineering Education Research Colloquies in the U.S. identified student conceptions of engineering and engineering epistemologies as priority areas of research for engineering education. Work in this area is still developing, though parallels can be drawn to the more established research on the nature of science and scientific inquiry (Lederman, 1992). Having a better understanding of students’ conceptions of engineering and how they are formed may: (1) tell us why students enrol and persist in engineering courses; (2) clarify critical connections between engineering education and practice; (3) illuminate potential naive beliefs about engineering; and, (4) provide insight for constructing curriculum and designing instructional approaches.

A search of the literature revealed a handful of published studies whose findings were relevant to this research study. Seymour and Hewitt (1994) investigated how science, technology, engineering and mathematics students experienced their university education and how their experiences related to their persistence in these fields. They conducted 335 ethnographic interviews across seven U.S. tertiary institutions and found that students who persisted in science, engineering, and mathematics were not significantly different from those who left these fields (in terms of high school and university grades). Instead, they found that the way students thought of classroom instruction, departmental culture, and interactions with peers and faculty were central in their decisions to persist in engineering.

In respect to research whose focus is explicitly on students' conceptions of engineering, much of the existing work has focused on primary and secondary education. With this age group, getting the children to "Draw-an-Engineer" is an instrument that has been used to capture conceptions of the engineering field. This instrument developed by Knight and Cunningham (2004) builds from theory on the extensive use of drawing [e.g., "Draw-a-Scientist" task (Chambers, 1983)] to capture understandings and perceptions of fields that are otherwise difficult to elicit. Studies by Cunningham et al. illustrate that pre-tertiary students' perceptions of engineering emphasise images of physical construction over mental aspects of engineering such as modelling and design thinking (Cunningham & Hester, 2007; Cunningham, Lachapelle, & Lindgren-Streicher, 2005).

There is a small but growing body of literature on tertiary students' conceptions of engineering and engineering practice. Most of the studies are at preliminary stages and use a variety of methods to get at these tertiary students' conceptions of the field. These methods include drawing, writing, photography, photo-elicitation (Oware, Diefes-Dux, & Adams, 2007) and of course, interviews. Lande and Leifer (2009) used a drawing method, derived from the "Draw-an-Engineer" instrument, to study first-year U.S. engineering masters students' conceptions of the role of a designer versus an engineer. They found that these students had distinct but complimentary ideas of a designer and an engineer. Designers were associated with idea generation, were human-centred, while engineers were associated with idea implementation, and were technology-centred. In a Singaporean context, Rajalingam (2009) conducted a pilot study on polytechnic students' conceptions of the engineering field, by requiring students to take photographs of what they associated with engineering and getting them to write about their photographs. He found that almost half of the participants still associated engineering with tangible physical aspects such as 'construction' and 'using technology' instead of more cognitive aspects such as 'teamwork', 'modelling' and 'design'. Thus far the most concerted effort to study tertiary students' engineering conceptions has been an exploration of "a Swedish perspective" on conceptions of engineering by the international Stepping Stones project group (Adams et al., 2007). Using surveys, concept maps, photo-elicitation and interviews the group has identified a broad spectrum of qualitatively different views on engineering to be investigated further. At the time this report was written, the final findings of the Stepping Stones study were not yet available. Given the sparseness of the literature in this area and the contextual nature of these types of studies, there is need for more grounded investigations in this area within various cultural contexts. The findings presented in the followings sections address this gap. Student conceptions related to the themes: (III) 'Beliefs about Engineering Knowledge'; (IV) 'Approaches to Solving Engineering Problems'; and, (V) 'Expectations of the Engineering Profession' are presented in Section 5.3.1, Section 5.3.2 and Section 5.3.3 respectively.

5.3.1 *Beliefs about Engineering Knowledge*

Beliefs about the nature of engineering knowledge are constantly evolving and a critical look at the culture of engineering has revealed that "what counts as an engineer and engineering knowledge has varied over time and from place to place" (Downey & Lucena, 2005, p. 252). Work by Stevens et al. (2008) has shown that students can encounter different images of engineering knowledge throughout their engineering education, and the beliefs they form about engineering knowledge are important elements in understanding how they become engineers. This section, describes the various beliefs that the participants hold about what counts as engineering knowledge. The four qualitatively different codes that were apparent from the interviews were beliefs that engineering is knowledge is gained by: (A) ‘Completing a List of Engineering Topics’; (B) ‘Applying Formulas to Solve Problems’; (C)‘Acquiring Technical “Hands-On” Skills’; and, (D)‘Understanding Scientific Concepts’. At the end of this section, Table 5. summarises the various approaches adopted by each of the nine participants to deal with mathematics.

A. <u>Completing a List of Engineering Topics</u>

When Rachel, a third-year student a few months shy of graduating, was asked, “What have you learnt from your three years of engineering studies?” her answer was:

> *For my course we covered all the different sciences - chemistry, bio and physics. But certain courses do not cover bio, but science plays a role because when it comes to engineering, physics comes into place. Physics is a kind of science also. It depends on how much it covers, but physics is always there when it comes to engineering.*

The sense that learning engineering was just coving a list of topics was one that a number of students seemed to share. When asked a similar question Tamir’s response was:

> *Ok, I take the diploma course in Communication and Automation Electronics…so this course what I learnt is about is like digital electronics, circuit design, communication systems, etcetera, you know? So to me it's like very big, as in there's a lot of things to cover.*

To be fair, most students offered a broader spectrum of views as to what counts as engineering knowledge when questioned further. There is a possibility that participants gave this initial response because they lacked the linguistic ability to communicate the intangible aspects of the knowledge that they associated with engineering.

B. Applying Formulas to Solve Problems

A major obstacle for participants is learning to deal with unfamiliar mathematics formulas that they encounter in their studies. Therefore, it is not surprising that the skill of knowing how to apply formulas to solve engineering problems emerged as a belief about what counts as engineering knowledge.

John in particular felt that this was the most important engineering skill he had learnt after three years.

> *I think it's using formulae, using numbers and figures to quantify the behaviour of something. Because electronics engineering I am studying about signals, about how waveforms all these things, behave inside the electronics, how electricity behaves, how the current flows.*

Lan too felt that knowing how to apply formula appropriately was important engineering knowledge, though it was something he struggled with at times.

> *For engineering there are formulae of course like math, but at the same time you have to relate these kinds of formulae to circuit diagrams. This kind of formulae to electronic, electrical theories and we need to understand both of these to explain what's going on.*

C. Acquiring Technical "Hands-On" Skills

The most pervasive and strongest belief amongst the participants about what counts as engineering knowledge, was the belief that engineering knowledge was different from other forms of knowledge because it involved acquiring practical technical skills. The participants implied that these skills were acquired by engaging in tasks that required them to create or do something with their hands. Eight of the nine participants mentioned this and most of them used the term "hands-on" to describe this type of knowledge.

A specific example of a "hands-on" engineering knowledge was the ability to solder components onto a circuit, as mentioned by Andi when he spoke of the difference between mathematics and engineering knowledge.

> *To me engineering and mathematics are a bit different. Engineering, there's a practical way in it whereas mathematics is 100% theory. There's not any practical things you need to do with mathematics. You just need to calculate, calculate and calculate. Whereas in engineering you need to solder all this kind of stuff.*

It seemed like it was the "hands-on" engineering knowledge that many of the participants related to and found the most useful. Fizal clearly appreciated the practical everyday things that this type of knowledge allowed him to do.

> *To me (engineering is) like doing up a circuit board, like constructing circuits, during my data communication module I was exposed to making cables, data cables whereby it's a wired cable whereby you can communicate between computers. That kind of 'hands-on' skills where we can apply it on our own, like those kind of things like maybe we can do on our own. Can buy the stuff from the shop and construct in our own home. That kind of thing I like. Constructing wiring and stuff. If there's simple wiring at home. Like change of wire, we might be able to perform it on our own.*

This type of "hands-on" knowledge is certainly pertinent to engineering especially at a polytechnic level. However, it would not be desirable for polytechnic graduates to focus on only this type knowledge without seeing the broader spectrum of engineering knowledge. Especially since they are expected by the Ministry of Education, Singapore to work as "practice-oriented and knowledgeable middle-level professionals" (Ministry of Education, 2011 in "Polytechnics", para. 1) and not just technicians after graduation.

D. <u>Understanding Scientific Concepts</u>

The final belief about what counts as engineering knowledge was the belief that it was necessary to understand important scientific theories and concepts such as Ohm's Law and Kirchhoff's Circuit Laws.

Fizal expressed this by saying that he had to truly understand the fundamental concepts behind Ohm's Law in order to know how the equations work.

> *For engineering there's part where you need to understand certain fundamental concepts. Maybe you have to know like Ohm's law, the fundamentals. If you don't know the fundamentals you wouldn't know how Ohm's law, the equation really works. So in order to know that particular equation you will have to know the fundamentals of how the equation is being derived theoretically.*

John also recognised the importance of scientific concepts in engineering. He realised that in order to learn about applied fields of engineering like data and mobile communications he had to understand scientific theories that describe the behaviour of radio waves.

> *The concept is for example, radio wave and frequency theory used in the data communications mobile communications modules. You have to know the concept very well in order to understand these things. So you need these two things. Logical thinking and understanding the concepts.*

The participants who held each of these four beliefs about the nature of engineering knowledge are summarised in the table on the following page, Table 5..

Table 5.3

Beliefs about what counts as engineering knowledge

Students believe that engineering is knowledge is gained by…

	Completing a List of Engineering Topics	Applying Formulas to Solve Problems	Acquiring Technical "Hands-On" Skills	Understanding Scientific Concepts
Vick	✓		✓	
Tamir	✓		✓	
Fizal		✓	✓	✓
Andi	✓		✓	
Rachel	✓	✓	✓	
John	✓	✓	✓	✓
Lan	✓	✓	✓	
Cai			✓	✓
Diana		✓		

The table demonstrates that most of the participants held more than one perspective as to what counts as engineering knowledge. The most common perspective of engineering knowledge, 'Acquiring Technical "Hands-On" Skills', is likely due to the greater emphasis on the acquisition of immediately applicable work skills in the polytechnic as compared to a university. These perspectives on engineering knowledge can also be thought of in terms of differing levels of sophistication. If so, 'Completing a List of Engineering Topics' seems to be the shallowest perspective, whereas 'Understanding Scientific Concepts' seemed to be that of a much deeper perspective of engineering knowledge. The other two perspectives appear to sit somewhere in-between in terms of sophistication.

5.3.2 *Approaches to Solving Engineering Problems*

In Section 5.2.2, participants' approaches to learning mathematics were discussed. In this section participants' approaches to solving engineering problems in the context of their diploma programmes is presented and explained. There is some overlap between participants' 'Approaches to Learning Mathematics' and their 'Approaches to Solving Engineering Problems' as will be discussed later in this chapter. A search of the engineering education literature uncovered only two preliminary projects over the last decade that sought to identify students' approaches to learning engineering in a PBL context (Krishnan, et al., 2006; Soundarrajan et al., 2007). Both of these projects sought to qualitatively describe the various student approaches, as does this study. However, in this study the intention is not to uncover the participant's approaches to learning engineering per se, but to uncover the various ways that they approach solving engineering problems. As problem solving is the main activity for learning in a PBL context, it could be argued that how students approach problem solving determines how they learn. The three different approaches of the participants to solving engineering problems were: (A) 'Start with What They Know'; (B) 'Analyse Worked Examples; and, (C) 'Just Apply the Right Formula'. Two of the approaches used to solve engineering problems, (B) and (C), were very similar to two other codes that relate to approaches to learning mathematics and were discussed in Section 5.2.2. The possible reasons for this overlap in approaches between learning mathematics and engineering problem solving are discussed later in this chapter. At the end of this section,

Table 5. summarises the various approaches adopted by each of the nine participants to solve the engineering problems that they encountered daily in their PBL context.

A. Start With What They Know

To many a layperson, it may seem improbable that students who have very poor mathematics ability would even be able to start solving a complex, mathematically dependent engineering problem. In reality, as demonstrated by the quantitative findings in Section 4.2.1 of the previous chapter, prior mathematics performance alone accounted for less than 5% of the variation in student GPA. Furthermore, since half of this GPA is computed from grades reflecting a student's daily processes in class (i.e., solving engineering problems), it can be concluded that lack of mathematics ability can be, and is, largely overcome by these students. One of the primary strategies employed by most of the participants in this study was to simply identify what they did know and start with that. This approach is called 'Start with What They Know'.

Cai describes this approach as:

> *I have learnt that the best thing to do is read though the problem slowly look for clues that relate to previous problems. I try to work from what we did previously. Much easier than jumping straight into the problem. We won't miss out on anything and maybe we will get better research and we won't go astray.*

Sometimes after agonising over a mathematically complex problem, a student may serendipitously see something familiar giving an inroad into the problem. Andi shared this method of working out an engineering problem.

> *What's my strategy (to solve a mathematically complex engineering problem)? Even though I don't know anything, I will stare at the numbers blindly and try to figure out what looks familiar. Eventually I can find something that I know where to start.*

Staring blindly at a problem is not the most tactical approach, but Andi's intention behind this approach was to look for something he knew to start with. The majority of the participants seemed to share this intention when adopting the 'Start With What They Know' approach.

B. <u>Analyse Worked Examples</u>

Four of the participants described an approach to solving an engineering problem that was coded as 'Analyse Worked Examples'. Worked examples are sometimes provide as part of the PBL problem package to serve as learning scaffolds for students. However, even when these worked examples were not provided, students were observed actively seeking out such examples on the internet and through other resources available to them. This engineering problem solving approach (analysing worked examples), was found to be analogous to the similarly named approach used to learn mathematics that was previously discussed in Section 5.2.2.

Fizal was one of the participants who relied extensively on worked examples. Instead of trying to figure out a worked example by himself, Fizal's tactic was to cajole his facilitator to go through a worked example from the internet.

> *To me the best approach is to bring a relevant example from the internet to the facilitator, then maybe, he teachers us the flow or the basic foundation of that example. From there at least we can relate to the problem for the day (PBL engineering problem) because at least we know something about it. And we are able to try to look up some answers and try to work it out.*

Diana too articulated a similar desire for worked examples to help with the engineering problems.

> *They should give us more engineering examples as resources. Examples that show us step by step, why is this formula used, and how it is being used, and why you would use that, and what to do next.*

Seeking out worked examples was one of the first things that many students were observed doing when they encountered an impasse in their problem solving. Using worked examples together with feedback has been demonstrated to be a promising technique for helping students develop engineering problem-solving skills by Moreno, Reisslein and Ozogul (2009). However, they acknowledged that a major challenge of depending on worked examples was to find methods that can help learners transition from studying fully worked-out problems to solving problems independently.

C. <u>Just Apply the Right Formula</u>

Four of the participants described this approach to solving engineering problems. This approach was again very much like a similarly named approach used to learn mathematics (as discussed in Section 5.2.2). In this case, the approach coded as 'Just Apply the Right Formula' can be thought of as executing the rules of particular formulas to complete an engineering task, without understanding underlying principles of the formula or its relationship with the other formulae. Once again, it is not unexpected that there is an overlap between how students would choose to approach mathematics and engineering. (More evidence for this overlap will be presented and discussed later in this chapter in Section 5.4.2.)

In the following quote John admits that he used this approach of 'Just Apply the Right Formula', even though he thought that it was not a learning strategy typically encouraged in PBL.

> *Well. It's quite going against the learning system. Just know the formula. What is this formula and apply into our UT (Understanding Test). One thing I understand about engineering is they want you to know this formula but they will not want to explore into this formula. Just know all the parameters to enter into the formula. And maybe a little bit of essentially how these formulas form. That's how I tackle this kind of thing.*

This quote also alludes to the strategic approach to learning that many students who were poor in mathematics needed to adopt in order to cope. John adopted such an approach despite recognising that deeper conceptions of learning were encouraged in the "learning system" he was in.

Rachel too spoke about how she often relied on this approach. However, she struggled with the fact that she did not always understand how the formulas worked.

> *When you try to solve (engineering) problems it's very difficult when you go on internet to find out what the steps are or the formula. Even if we find the formula, we can apply without knowing how it works. So it's very difficult sometimes. End of the day you still don't know how it has happened. When you see that others in your class have done, even when you ask them sometimes it's like their way of applying it will be different from how you want to apply it.*

Rachel's dissatisfaction with this approach seems to stem from the fact that she was not confident that her applications of the formulas were right. Without understanding the formulas, she simply attempted to gauge if she had applied them correctly by comparing with her peers.

The approaches towards solving engineering problems adopted by each of the study participants are summarised in the following table.

Table 5.4

Approaches to solving engineering problems

The students' approach to solve engineering problems is to…

	Start With What They Know	Analyse Worked Examples	Just Apply the Right Formula
Vick	✓		✓
Tamir		✓	
Fizal	✓	✓	
Andi	✓		
Rachel	✓	✓	✓
John	✓		✓
Lan	✓		
Cai	✓		✓
Diana		✓	

Participants' approaches to solving engineering problems seemed to be less diverse than their spectrum of approaches to learn mathematics. In general, they also had more to say about approaches to mathematics than approaches to engineering. The most predominant approach to solving engineering problems was to look for something familiar and just start with that, as represented by the code 'Start With What They Know'. The two other approaches mentioned by the participants, 'Analyse Worked Examples' and 'Just Apply the Right Formula' indicate that even when different approaches are adopted, these approaches were closely related to mathematics. These two approaches also resonate with previous work done in approaches to learning in engineering education contexts by Case and Marshall (2004). They describe an approach in engineering education termed a 'procedural approach' where the strategy of students is either to "relate formulae to each other, or parts of algorithms to other parts" or to "identify and memorise calculation methods for solving problems". By this description, 'procedural approaches' seem to be the predominant approach adopted by participants to solve engineering problems.

5.3.3 *Expectations of the Engineering Profession*

The obvious purpose of educating engineering students is so that that most of them will become engineers or do engineering work. Underlying this is an assumption that graduating engineering students readily envision what it means to be an engineer, and what type of work they will be doing as engineers in the future. Matusovich et al. (2009) conducted a qualitative study that tested this assumption and found that graduating university students' self-perceptions of being engineers in the future included expectations of themselves being good in math and science, being good communicators, being good at teamwork, enjoying activities they believed engineers do, doing problem-solving, and applying technical knowledge. They also found that despite almost four years in engineering-related classes and activities, three of ten participants remained unsure of what it meant to be an engineer. This section presents findings that address a similar issue to the Matusovich et al. (2009) study. Specifically, the findings in this section characterise the different ways that engineering diploma students who are weak in mathematics, envision their future engineering work and the engineering profession.

The four ways that that participants characterised their expectations of the engineering profession during interviews were: (A) 'Involves Teamwork; (B) 'Understands Technology'; (C) 'Solves Authentic Problems'; and, (D) 'Is Intrinsically Rewarding'. Two of the participants, Vick and Tamir, admitted during their interviews that that did not really know what to expect of future engineering work or the engineering profession. Further questioning reinforced the truth of this confession, as neither participant was able to contribute to any of the abovementioned codes. At the end of this section, summarises the various expectation of the engineering profession held by each of the nine participants.

A. Involves Teamwork

The expectation that future engineering work probably 'Involves Teamwork' was a theme recognised by two of the nine participants. That the present-day engineering workplace involves teamwork, is a fact often taken as a given by most professional engineers (Taninecz, 1996). Indeed, the need to train engineering students to work effectively in teams is one of the key arguments for adopting a PBL or a Project-Based curriculum in engineering (Mills & Treagust, 2003). It is therefore somewhat underwhelming, that that only two participants emphasised this expectation of future engineering work, given the amount of teamwork all of the participants have to engage in daily. One possible explanation is that teamwork is so much of an everyday occurrence for the participants that it failed to get special mention. Some of the participants may have considered teamwork a given for engineering work, and neglected to mention it during the interview.

One of the two participants who did speak about teamwork in the engineering was Lan.

> *It's important (Teamwork). Because in engineering you need to help one another. I helped my whole class to solve a particular problem in one of the modules that I learnt in ITE (Institute of Technical Education). When I do not*

> *know the problem of the day, I go to my teammates and they also helped me. Usually you need help from each other. You can't just do it alone.*

Cai was the other participant who mentioned teamwork. He described a situation where he felt that he and his classmates actually solved a realistic engineering problem by collaborating.

> *There was one time we had this real-life problem, were we had to fill up this complex table (Karnaugh map) in digital electronics. The whole class, even a few groups from other classes actually came together and we discussed how to fill it in. So I think that's one way to encounter, to tackle an engineering problem.*

Today, employers are placing a greater emphasis on teamwork, and there are calls for engineering education to respond by adopting more structured approaches, such as PBL, in order to develop teamwork skills (Smith, et al., 2005). It is hoped that like Cai, more engineering student can see how these skills relate to real engineering work.

B. Understands Technology

One need only look at the ubiquitous use of smart phones in the last few years to get a sense of the rapid penetration and influence of technology in everyday life. A 2004 poll (Rose, Gallup, Dugger Jr, & Starkweather) by the International Technology Education Association on how adults think about technology, found that most people valued knowing how various technologies work. Two thirds of the respondents also believed that technology was the same as engineering. This may be a simplistic view of engineering. However, it could well be argued that there is a significant overlap between knowing how technology works and being a good engineer. Five of the engineering students in this study also expressed the view that engineering involves ‘Understands Technology’.

For example, Cai in the following quote shared how his knowledge of Digital Electronics could help him to better understand the technology around him.

> *Maybe let’s say what I’ve learnt in Digital Electronics. I walk into a lift or anything, I can understand more than the other people how it works. I know something about the (micro) chip in the lift, what it does, what it can do, and then I think hey, I can implement this inside this system, or maybe this system is something like this another system.*

Andi made the association between the engineering profession and ‘Understanding Technology’ during his interview. He felt that compared to the layperson, engineers have a better understating of how technological things work.

> *Everyone uses technology in everyday life. But an engineer will understand when you switch on the TV how the electronics and the screen works. How the electricity flow from the power station to here or how does everything go about in your car. Not everyone knows this.*

While the public may view engineering as synonymous with technology, the participants in this study did not have the same one-dimensional view. Each of the five participants who associated engineering with 'Understanding Technology' also put forth at least one other expectation of engineering and the engineering profession during the interviews.

C. Solves Authentic Problems

Practicing engineers are hired, retained, and rewarded for solving authentic problems, which are complex, ambiguous and ill-structured (Jonassen, et al., 2006). Therefore, it is expected that engineering students realise before they graduate, that problem solving is an essential engineering skill. Four of the participants shared this perspective of engineering (i.e., that was coded as 'Solves Authentic Problems'). Given that the importance of problem solving was emphasised to the participants daily through PBL, it would have been a surprise if none of them made the association between the ability to solve problems and being a good engineer.

Diana clearly held this expectation of her future engineering profession. It fact, it was the only conception of the engineering profession that she repeatedly expressed during the interviews.

> *I did process mapping for my FYP (Final Year Project) which is very useful in the future because you can actually help a company to identify and solve problems with their processes. You could actually help to propose your solutions to them and they will help the company.*

Of all the participants Cai made the clearest declaration that an engineer actually 'Solves Authentic Problems'. In the following quote, he expresses that he holds this opinion, despite conflicting information from some of his facilitators.

> *I think solving problems is the biggest thing engineering does. Every time few of my facilitators say as an engineer you must do this and do that. From what I feel, the big thing engineers do is, take what the problems real world is offering including all those financial issues, etcetera and implement it in the real world.*

D. Is Intrinsically Rewarding

The final conception of the engineering profession, expressed by five of the participants, was that they expected engineering work to be intrinsically motivating or rewarding. For example, descriptions of engineering as interesting or fun were interpreted as references to the belief that engineering 'Is Intrinsically Rewarding'. The level of intrinsic reward to study engineering was found to be an indicator of students' performance in their studies and their persistence in the engineering field (French, et al., 2005). Other research has shown that first-year female engineering students expected the engineering profession to be less intrinsically rewarding than their male counterparts, and this could affect their persistence in the field (Kilgore, Yasuhara, Saleem, & Atman, 2007). While research has been done that indicates that PBL positively influences immediate motivation to study engineering (Galand, Bourgeois, & Frenay, 2005), it is not known if PBL has an impact on student perceptions of future engineering work.

Lan in the quote below expressed the view that he found engineering intrinsically rewarding because it allowed him to understand how everyday technology worked.

> *Generally, I learnt engineering is a very interesting world actually, because it teaches me about how all the components, how all the daily things that require electronics work, they need to be understood further and deeper.*

Rachel shared how engineering work while sometimes tough was satisfying to her, especially when she got something to work.

> *When you do something and it's really very hard doing it and at the end of the day you see it working wow it's like you can show it to everyone. This is something I did and it works. It keeps you moving. When something does not work the curiosity is there. Why does it not work when someone else's does?*

The expectations of the engineering profession and future engineering work held by each participant are summarised in the following table,

Table 5.5

Expectations of the engineering profession

Students think that the engineering profession…

	Involves Teamwork	Understands Technology	Solves Authentic Problems	Is Intrinsically Rewarding
Vick				
Tamir				
Fizal			✓	✓
Andi		✓	✓	
Rachel		✓		✓
John		✓		✓
Lan	✓	✓		✓
Cai	✓	✓	✓	✓
Diana			✓	

The table (5.4 above) gives an indication of how varied students can be in the amount that they think and know about the engineering profession. Vick and Tamir could hardly put forth anything concrete about their future expectations though both had a lot to contribute about their current experience. In contrast to this is Cai, he had by far the broadest and most developed conceptions of the engineering profession, and some of the most insightful quotes in this section came from him. From the interviews, Cai also came across as the most motivated and clear about his educational goals. One reason for him standing out in this respect could be his mature age (25 years old at the time of the study). It should also be noted that Cai went on to graduate as one the top five engineering students in his cohort after this study was completed.

5.4 ***Research Question 4: A Data Grounded Explanation***

In the preceding sections, the qualitatively different codes that make up the five themes in this study were presented and discussed. In these final sections, the relationship between these five themes will be established and explained, with evidence from participants' interviews. Simple models within each section aid in the visualisation of the relationships between themes. However, a final model that encapsulates all the relationships between these five themes and the broader categories to which the themes are linked, is presented in Section 5.5, the summary of this chapter.

5.4.1 *Relationship between Beliefs and Approaches in Mathematics*

With regard to the relationship between the two themes associated with mathematics, the data indicates that participants' 'Beliefs about Mathematics' affected their 'Approaches to Learning Mathematics'. It has been suggested that participants' experiences with mathematics prior to enrolment in the polytechnic influenced their 'Beliefs about Mathematics'. At least one recent study has shown that previous experiences with mathematics can be both supportive and problematic in learning mathematics (McGowen & Tall, 2010). The relationship between participants' current beliefs and approaches in mathematics is shown in Figure 5.2, following.

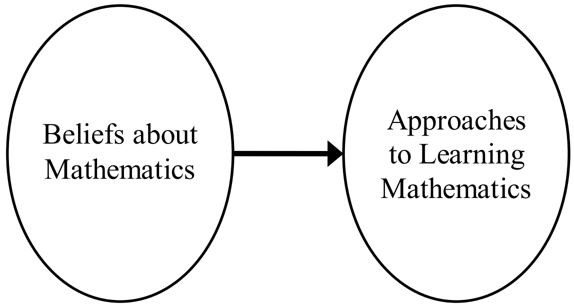


Figure 5.2 - Relationship between beliefs about and approaches to learning mathematics

The proposition is that prior beliefs affect learning approaches in mathematics, is evidenced in the participant quotes that follow. For example, Fizal's belief that mathematics was somewhat formulaic was his justification for choosing a particular approach to learn mathematics.

> *It's kind of difficult for me to adapt so quickly because for mathematics it's more of a practice rather then come out from the internet with formulae and stuff,* ***[Beliefs about Mathematics]*** *because there is so much you can know about formulae but to really apply you have to feed information* ***[Approaches to Learning Mathematics]*** *before you can apply it to really work.*

Tamir also seemed to have the belief that mathematics was formulaic, and this perspective led him to adopt a 'Listen and Remember' approach to learning mathematics.

> *There are tons and tons of formulae* ***[Beliefs about Mathematics]****. It's very confusing. There are a lot of terms so if I am to remember each and every one. I am not the type who can remember things…short term memory* ***[Approaches to Learning Mathematics]****.*

This idea that students' beliefs about mathematics affected their approaches to learning that subject was also reached in other comparable studies on mathematics (Crawford, et al., 1998a; Crawford, et al., 1998b), and there is a significant body of earlier work in general education that relates to this (Biggs, 1979; Marton & Saljo, 1976). The findings presented here reinforce that proposition.

5.4.2 *Overlap between Mathematics and Engineering Approaches*

One question that needs to be answered is "how do these students' conceptions of mathematics relate to their conceptions of engineering?" The participant interviews indicated that there was an overlap between 'Approaches to Learning Mathematics' and 'Approaches to Solving Engineering Problems as shown in Figure 5.3. In particular, the approaches of 'Analysing Worked Examples' and 'Just Apply the Right Formula' were used by the participants interchangeably for both mathematics and engineering.

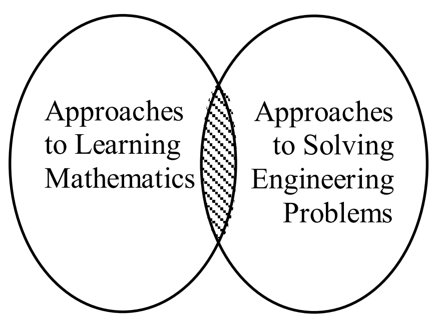


Figure 5.3 - Overlap between approaches to learning mathematics and solving engineering problems

The following participant quotes give evidence in relation to this overlap in approaches. Vick in the following quote described why he felt that the themes of learning mathematics and solving engineering problems were similar. From his interviews, he indicated that he often adopted a 'Just Apply the Right Formula' approach in both cases.

> *For example simultaneous equations, you find one and then you substitute and then you carry on* ***[Approaches to Learning Mathematics]****. In Engineering, there are some forms like that. Usually in circuit analysis when you do super position, so if there's two circuits given you short one circuit, you complete one circuit then you come back to the second circuit* ***[Approaches to Solving Engineering Problems]****. In that way, you see there's this similarity.*

In the following quote, Fizal describes what his facilitator does that he feels most helps him learn. In his interviews, Fizal described using the 'Analyse Worked Example' approach for both mathematics and engineering. This overlap in his approaches is also indicated, where he mentions using the same approach in the start and end of the day. Usually by the end of the day, students should be working on a complete solution to the engineering problem for the day not trying to figure out the mathematics.

> *At the start of the day he tried to present us an example. Give us, how to derive to the formula in the problem* ***[Approaches to Learning Mathematics]****. After that, end of the day he will give us another set which looks similar but is more detailed with additional questions and he will tell us to derive the equation* ***[Approaches to Solving Engineering Problems]****.*

An explanation for these students adopting a similar approach for engineering and mathematics is that many of them start their engineering studies without well-defined beliefs about the nature of engineering knowledge. Therefore, they try to overcome difficulties with engineering problems, which they see as mathematical in nature, by using strategies that they already use in mathematics. Since these students likely have below average ability in mathematics, reusing these strategies may be futile and even discouraging for them.

5.4.3 *Relationship between Beliefs, Approaches and Expectations in Engineering*

It has been shown in the previous two sections that 'Beliefs about Mathematics' affect 'Approaches to Learning Mathematics', which in turn overlap with 'Approaches to Solving Engineering Problems'. This section examines the relationship between the three conceptions associated with engineering. The data indicates that contrary to mathematics, approaches affect beliefs in engineering. Furthermore, 'Beliefs about Engineering Knowledge' affect 'Expectations of the Engineering Profession'. This relationship is illustrated in Figure 5.4, below.

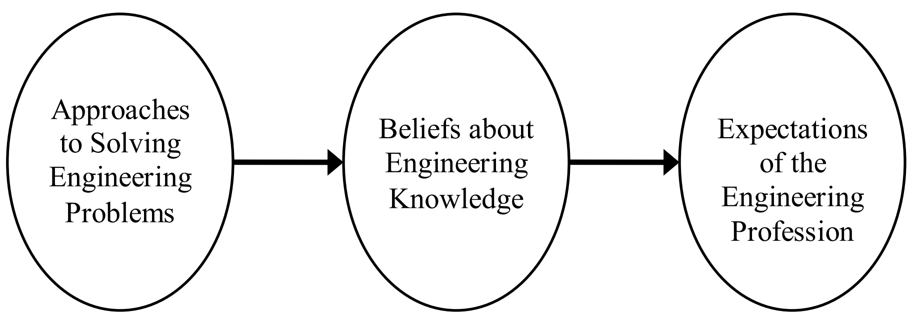


Figure 5.4 - Relationship between approaches to solving engineering problems, beliefs about engineering knowledge and expectations of the engineering profession

The following quotes by John, Diana and Lan, show evidence for this relationship. John shares his beliefs and approaches to engineering in the following quote. From notes during the interview and his words below, it can be inferred that the approaches he employed to solve problems helped to shape his beliefs about engineering knowledge. This pattern was also observed in the statements from other students. Though intuitively it would seem that beliefs about knowledge shape approaches to learning rather than vice-versa, seminal work by Ramsden (1992) on students' perceptions of the learning context has shown that converse can be true as well. Ramsden (1992, p. 84) stresses that this relationship should not be taken to suggest a single one-directional causal sequence of events, but that the elements interact in a complex way with each other.

> *I think it's using formulae, using numbers and figures to quantify the behaviour of something* ***[Approaches to Solving Engineering Problems]****. Because electrical engineering I am studying about signals, about how waveforms all these things, behave inside the electronics, how electricity behaves, how the current flows* ***[Beliefs about Engineering Knowledge]****. So actually, engineering is trying to use formulae and figures to quantify and let us understand the behaviour through these figures* ***[Approaches to Solving Engineering Problems]****. That's the thing that I get from it.*

Diana's quote illustrates how her beliefs about engineering shape her expectations of engineering work. Diana believed that engineering knowledge was fixed and consisted principally of 'Applying Formulas to Solve Problems'. This led her to have poor expectations of the engineering profession, as she thought that she lacked the inherent ability to cope with engineering work as compared with her peers.

> *Really sometimes I feel that engineering is really all about math. If you're able to do well in math right you should have those very logical thinking, systematic thinking which engineering requires you to have because of all the theories. It's all fixed so it's what is usually mathematical* ***[Beliefs about Engineering Knowledge]****. Because their (her classmates') brain is really quite inclined towards that area so they are able to cope with engineering stuff, not me* ***[Expectations of the Engineering Profession]****.*

Lan expresses all three themes related to 'Conception of Engineering'. His positive expectations of the engineering profession were shaped by his beliefs about what counted as engineering knowledge. He also made reference to his approach to solving engineering problems in the following quote.

> *Generally I learnt Engineering is a very interesting world actually* ***[Expectations of the Engineering Profession]****, because it teaches me about how all the components, how all the things that require electronics, they need to be understood further and deeper* ***[Beliefs about Engineering Knowledge]****. So engineering is like, even though it's complicated sometimes, but at the same time, the way engineering is like the calculations part, the way the engineering world makes us think deeper and stress us up that kind of thing* ***[Approaches to Solving Engineering Problems]****. It makes it more, like fun, interesting and*

> *sometimes I think I feel like going to university, go on, go engineering and so on, but all is just a thought lah* ***[Expectations of the Engineering Profession]***.

The models and data presented indicate how 'Conceptions of learning Engineering' are initially shaped by prior 'Conceptions of learning Mathematics' and develop further through encounters with engineering knowledge and problems in an engineering course. The overarching narrative of the findings is that students' prior conceptions of mathematics cannot be ignored as they are the starting point for their conceptions of engineering, which in turn shapes their experience of learning engineering. It is likely that students who are weak in mathematics, have both deep-rooted conceptions of mathematics (even if these conceptions are inaccurate) and undeveloped conceptions of engineering. Because of this, the engineering conceptions that these students form while learning engineering are likely to be strongly influenced by their conceptions and even misconceptions of mathematics.

A model summarising this relationship between the conception of mathematics and engineering is presented in the next section. The way that students end up conceptualising engineering is also likely to have an impact on both the psychological characteristics associated with learning and engineering education outcomes, as proposed by the theoretical model in the next chapter.

5.5 ***Summary of Findings from the Student Interviews***

At the start of this chapter, the five themes that emerged from the analysis of the interview transcripts were briefly described. Each of these five themes relates to either student

'Conception of Mathematics' or 'Conception of Engineering'. The rich interview data, have given a picture of the qualitatively different beliefs, approaches and expectations that these students have of the subject domains of mathematics and engineering. The subsequent presentation of the data relating to each theme has provided considerable elaboration on the nature of both of these conceptions, thereby answering Research Questions 2 and 3. Further analysis of this data also uncovered the connections between the various themes, and has demonstrated an overlap between students' conceptions of mathematics and engineering. These findings thereby partially address Research Question 4. A model that illustrates these connections has been constructed and is presented below in Figure 5.5.

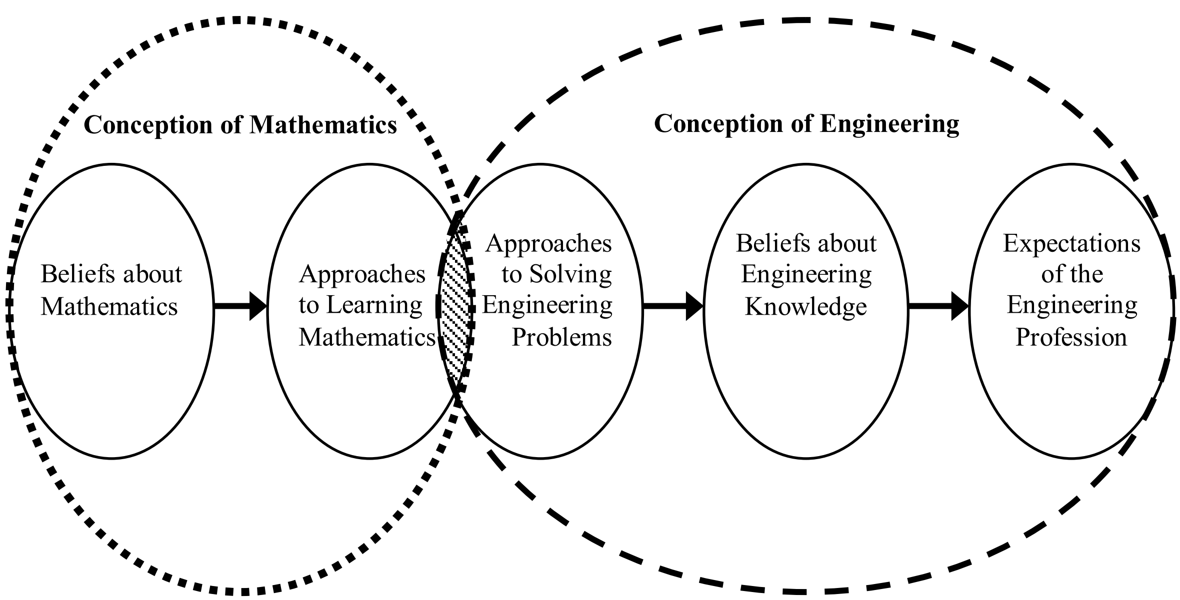


Figure 5.5 - Model of the overlap between students 'Conception of Mathematics' and 'Conception of Engineering'

The findings in this chapter have demonstrated how ‘Conception of Mathematics’ and ‘Conception of Engineering’ influence each other and influence the process of learning engineering. Both of these conceptions in turn link to the core category of this research, which are students’ ‘Conceptualisation of Various Subject Domains’. There is a dearth of research related to this area of engineering education. One study in this area (Palmer & Marra, 2004), has shown that engineering students’ epistemological conceptions differ across the disciplinary areas of the sciences and the humanities. Others have studied engineering students’ conceptions of understating mathematics within the context of engineering (Khiat, 2010). However, no research was encountered that explored how a student’s conception of one subject domain (e.g., mathematics) may affect the development of his conception of another related domain (e.g., engineering). For students who are weak in mathematics this is something that greatly affects their overall experience of learning engineering, as evidenced by their interview data.

A clear and in-depth understanding of these engineering students’ conceptions of mathematics and engineering is important to the students themselves and their engineering educators. For the educator, these insights allow him or her to emphasise useful conceptions of engineering to students who may have formed misconceptions about the field. The engineering professor is also able to adjust his or her instructional strategies accordingly to ensure that students learn about the true nature of the engineering profession, instead of building up a false image based solely upon existing conceptions and/or misconceptions. The benefit to students is that they can meaningfully alter their learning strategies by understanding others’ conceptions of mathematics and engineering. In particular, a student could avoid the pitfalls of applying inappropriate approaches in engineering problem solving because of a belief about the nature of engineering mathematics.

Perhaps even more importantly, these findings offer insights into the perspectives of a generation of future engineers and provide an explanation as to why they persist in or leave the field. As mentioned in the introduction to this chapter, a significant goal of this study was to describe the participants' conceptions, and explain how these conceptions are developed. The qualitative findings presented in this chapter contribute to achieving this goal. The theoretical model, developed and proposed in the following chapter, builds on these findings to suggest how conceptions of engineering play a central role in engineering education.

Chapter 6 Response to the Research Problem: Interpretation of the Overall Findings

The key research gap that this thesis attempts to fill is a lack of understanding of how prior mathematics failure, affected the learning experiences and outcomes of students who were studying for an engineering diploma in a PBL context. The previous two chapters have partially addressed this problem by answering the four main research questions. The purpose of this chapter is to bring together and analyse the findings of the previous chapters, and thus fully address the main research problem outlined in Chapter 1.

In the analysis reported in Chapter 4, it was established that students' prior mathematics performance in the GCE 'O' level by itself explained very little of the variation (7%) in their academic performance. By modelling the effects of students' prior mathematics performance as well as their confidence and disengagement in engineering related subjects, more of the variation (21%) in academic performance could be explained. Moreover, Chapter 4 established that prior mathematics performance was most strongly linked to students' desire to persist in the engineering field after graduation. This outcome is also known as professional persistence. The influence of prior performance on professional persistence was observed indirectly through two moderating factors, namely confidence in mathematics and science skills and intrinsic motivation to do engineering.

Chapter 5 established that students' conceptions of mathematics were integral in shaping their conceptions of engineering. The qualitative data indicated that for the majority of the student participants, there was a strong overlap between conceptions of mathematics and conceptions of engineering. The students' conceptions of engineering in particular, included expectations of the engineering profession, and seemed to be linked to future career choices.

These findings (which were discussed in depth in the previous chapters), have now set the stage for a more interpretative and theoretical approach to the data. This progression from description (where the data have been structured to show patterns and summarised), to interpretation (where there is an attempt to theorise the significance, meanings and implications of the patterns and their relation to previous literature), is an ideal approach to qualitative analysis (Patton, 2002). This chapter, (Chapter 6), presents the interpretation of patterns across both quantitative and qualitative datasets, and shows how students' conceptions of mathematics and engineering are intimately tied to their academic confidence and intrinsic motivation. This interpretation of the data resulted in a substantive theory of the situation being studied, which will be developed and presented in the subsequent sections.

6.1 ***A Theoretical Framework for Interpreting the Findings***

Central to the findings in the previous two chapters is the idea that poor prior mathematics performance had an effect on student academic confidence and intrinsic motivation, and it also affected how students' conceptions of engineering were formed. All of these constructs in turn affected other outcomes of engineering education, such as students' current academic performance and their intention to persist in an engineering related field after graduation. So far, in this study, most of the key findings were grounded in the data. This meant that findings could be induced from the observed data without necessarily making explicit deductions from the established educational theories. From this point of the study onwards the analysis becomes more theoretically driven, meaning that it seeks to find theoretically grounded interpretations for the findings presented in the earlier chapters. Therefore, it is appropriate to introduce a theoretical framework at this stage. This framework can be thought of as a basis for theoretically linking some of the constructs that were discussed in earlier chapters.

The theoretical framework draws upon three well-established theories in the field of educational research. These theories are 'Ramsden's Model of Student Learning in Context', 'Self-efficacy Theory' and 'Expectancy-value Theory'. These three theories were chosen following an examination of the research findings and a critical review of the educational literature. The following sections review the origin and formulation of these theories, describes how they have previously been used in educational research, and explains the choice of these theories for this study.

6.1.1 *Ramsden's Model of Student Learning in Context*

Paul Ramsden's influential work on students' conceptions of the context of teaching and learning, forms one of the key elements of the theoretical framework for this study. This section elaborates on Ramsden's theory and discusses how the model he proposed can be applied to the findings presented in the earlier chapters. Ramsden's early work in the area was first published in the widely cited book, 'The Experience of Learning' (Marton &

Entwistle, 1984). Here Ramsden laid out his theoretical ideas of this area and formulated a set of 'interconnected levels' which influence students' conceptions of the educational context. These levels were: (1) the student's interest, knowledge base, and previous experience; (2) assessment; (3) teaching and teachers; and, (4) course design, department and institution. Of these four levels the first level, which is concerned with characteristics of the student, is most commonly used by educators to explain why students do not achieve anticipated learning outcomes. This approach has to be employed with caution, as it is too easy to blame failure to achieve learning outcomes on student characteristics thus conveniently excusing educators from having to question their own methods of assessment, teaching and curriculum. However, that said, there are good reasons to focus on this first level. One good reason encompasses that of where the end goal of the research is to modify methods of assessment, teaching or curriculum in response to the student's interest, knowledge base, or previous experience; as is the aim of this study.

Ramsden represented the relationship between students' perceptions, approaches to learning, learning outcomes and the four different levels of context graphically in a model. The approaches to learning that students demonstrate in particular contexts were assumed to be fundamentally influenced by students' perceptions of those contexts. The model developed by Ramsden was intended to provide a basic theoretical exposition of this idea. A generic version of this model is given in Figure 6.1, below.

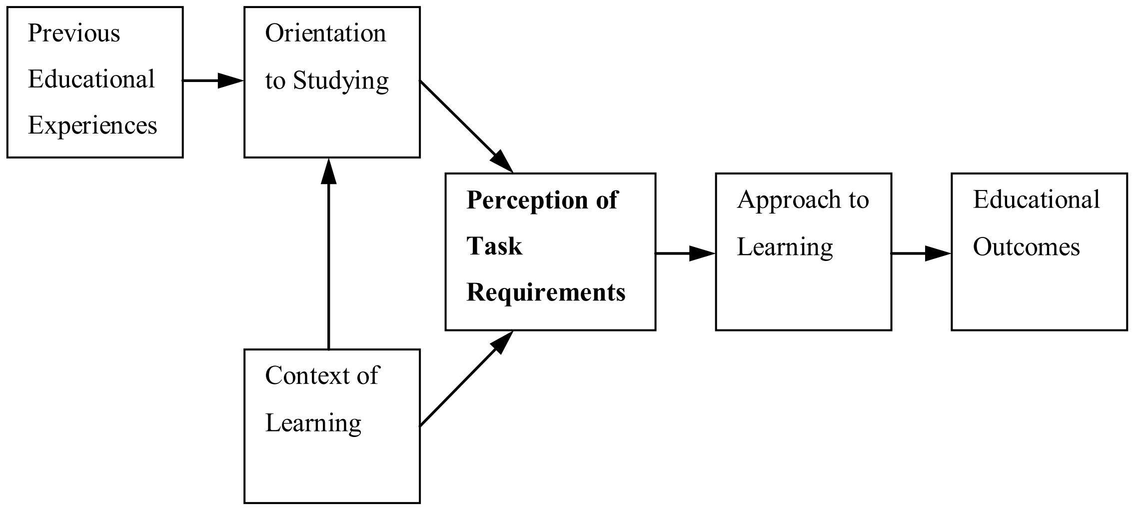


Figure 6.1 - Ramsden's 'Model of Student Learning in Context' adapted from (Ramsden, 1992, p. 83)

This model is derivative of another influential educational model, Biggs' Presage, Process and Product Model of Student Learning (Biggs, 1989). Nonetheless, Ramsden's model is unique because it highlights the central role of student perceptions. Ramsden emphasised that students respond and react to the situation they perceive, which is often quite different from what educators and researchers define. In this model, the four levels mentioned earlier lie on the left and are subsumed within the constructs 'orientation to studying' and 'context of learning'. Both of these constructs directly influence 'perception of task requirements'. However, the arrows in the model should not be misinterpreted as advocating a single causal sequence of events. Ramsden himself stressed that the constructs in the model were connected by a "chain of interactions at different levels of generality" (Ramsden, 1992, p. 84).

In engineering education in particular, this model has been used successfully by Case and Gunstone (2003a, 2003b) as part of a theoretical framework to analyse engineering students' perceptions of the learning context and approaches to learning. The learning context of their study was a second-year chemical engineering course in a South African University. Case and Gunstone identified three approaches to learning in engineering students: (1) a 'conceptual approach' in which the student's goal was to understand concepts; (2) an 'algorithmic approach' in which the student's focus was on calculation methods; and, (3) an 'information-based approach' in which the student's goal was to gather and remember information. They also found that separate from approach to learning, all students demonstrated one of two different perceptions of time within their learning context. One was a perception of 'being in control' of time and the other a perception of 'being out of control' of time. They asserted that students using a 'conceptual approach' differed from students using other approaches in the way that they chose to allocate time to various learning activities. For students not already adopting a 'conceptual approach', the authors claimed that the highly time-pressured environment in the engineering course discouraged students from shifting towards a 'conceptual approach'.

Ramsden's model is extremely useful in reinforcing the links between the perceptions, approaches and outcomes that have been presented in the previous chapter of this thesis. In reference to this model, the 'context of learning' for this study is the unique PBL educational approach that was described in detail in Chapter 1. The educational approach described in this chapter is adopted consistently across the entire institution, meaning that the teaching method, curriculum and assessment are relatively uniform for all students. For this reason, it is likely that the students' 'previous educational experiences' and 'orientations to studying' are the variable factors that influence 'perceptions of task requirements'.

The findings that were presented in Chapter 5 centre on these 'perceptions of task requirements'. More specifically, they demonstrate that the prior mathematics failure of some students in the GCE 'O' Level greatly influenced how they conceptualised learning engineering, within the PBL context. Chapter 5 also discussed the various conceptions held by the student participants of the learning context, and showed how these various conceptions related to one another. By using Ramsden's model as a theoretical lens as Case and Gunstone (2003a, 2003b) did, these findings have been interpreted in a new light and will be discussed in the subsequent sections of this chapter.

6.1.2 *Self-efficacy Theory*

Self-efficacy theory came out of Albert Bandura's work on broader social cognitive theories, which suggested that an individual′s behaviour, environment, and cognitive factors are all highly inter-related. Self-efficacy is a psychological construct that is concerned with a person's beliefs about his or her own competence to complete a certain task.

Bandura (1977, 1982) described self-efficacy related beliefs as personal judgments about one's generative capability for cognitive, behavioural, social, and emotional actions, that vary in terms of their level, generality and strength. These beliefs, also known as competence beliefs, are derived through processing information from four sources: (1)

mastery experiences (i.e., one's previous performances); (2) vicarious experiences of observing others' performances (i.e., social comparisons with peers); (3) social persuasion (i.e., where one is convinced, through suggestion, that they can cope successfully with specific tasks); and, (4) current physiological or emotional states (Bandura, 1986). In addition, Bandura (1997) clearly stated that self-efficacy related beliefs are not generalised or immutable personality traits, rather they change over time and with additional experience. Self-efficacy theory is an important part of understanding students' involvement in the educational context as it is linked to the types of activities that they choose to participate in, the level of effort they expend, their degree of persistence in those activities, and their level of performance (Bandura & Cervone, 1983, 1986).

In regards to engineering education, self-efficacy theory has emerged as an important theoretical perspective for understanding first-year students' experiences (Hutchison-Green, Follman, & Bodner, 2008; Hutchison, Follman, Sumpter, & Bodner, 2006). These researchers found that the self-efficacy related beliefs of undergraduate engineering students in a U.S. context were influenced by performance comparisons based on the speed with which they were able to perform various tasks, the degree of contribution they achieved when working with others, how much material they had mastered, and their grades. They also discovered that although student rankings of the most significant factors varied little by gender, more women than men reported factors related to understanding, learning, and help as influences on self-efficacy related beliefs. In a subsequent analysis of interviews, the researchers found that whereas both men and women reported that their self-efficacy related beliefs were significantly influenced by performance comparisons, the effects of such comparisons were more often positive for men and negative for women.

In a comparable study, Marra, Rodgers, Shen, and Bogue (2009) presented the results of a cross-institutional analysis of women engineering students' self-efficacy that was conducted over two years and included students at various stages of the curriculum. Their results were mixed, indicating positive gains in some areas of self-efficacy subscales and losses in others, along with persistent challenges involving inclusion and belonging. Earlier analysis of similar data from a three-year study across five institutions also demonstrated a strong link between self-efficacy and persistence in engineering programmes for both men and women (Marra & Bogue, 2007).

Most recently Jones, Paretti, Hein, and Knott (2010), found that engineering students' self-efficacy related beliefs decreased over the first-year for both men and women. They also found that men reported higher levels of self-efficacy compared to women, thereby reinforcing the findings of previous research in this area. Finally, they discovered that self-efficacy was somewhat predictive of academic achievement in engineering courses, but not of career plans for both men and women.

Self-efficacy theory has established itself as a useful theoretical perspective to understand gender differences in engineering education. Therefore, it stands to reason that it may also be a useful perspective to understand other differences, such as the difference between students with different prior mathematical experiences.

In the findings presented in Chapter 4, student confidence in mathematics and science skills emerged as an important factor that affected the learning process of students who were weak in mathematics. Bandura (1997, p. 382) makes a distinction between self-efficacy and confidence, claiming that while the two constructs are related "confidence" is a nondescript term that refers to strength of belief but does not necessarily specify what the belief is about. In other words, he claims that self-efficacy is a more specific and theoretically useful construct than confidence. Others authors have taken a more charitable view of the construct of confidence. Schunk (1991, p. 212) claims that of all the other self-constructs that relate to social cognitive theory, "self-confidence appears the most akin to self-efficacy". In practice, a number of validated survey instruments that measure self-efficacy (Baldwin, Ebert-May, & Burns, 1999; French, et al., 2005; Hocevar, Hagedorn, & Vogt, 2007) use the term "confidence" extensively in their questions, possibly because of the nearly indistinguishable boundary between these two constructs.

Others (Baldwin, et al., 1999; French, et al., 2005; Hocevar, et al., 2007) have hypothesised that confidence in an academic setting is a distinct construct that can be derived from the parent concept of self-efficacy. They posit that this construct could be useful to highlight differences among students in higher education. Sander and Sanders (2006, p. 33), call this construct 'academic confidence' and conceptualise it as being "how students differ in the extent to which they have a strong belief, firm trust, or sure expectation in their ability to respond to the demands of studying at university".

Sander and Sanders (2006) claim that similar to self-efficacy, academic confidence is likely to be primarily determined by mastery experiences but in addition it may be affected by a plethora of social factors from both within and around the educational process. Outside the context of engineering education, there is a wealth of evidence showing that self-efficacy is strongly linked to academic confidence (Chemers, Hu, & Garcia, 2001; Jimenez Soffa, 2007; Pajares, 2006). Within engineering education, at least one multi-institution study of 713 engineering students across majors and years of study (Vogt, 2008), has reported strong correlations between self-efficacy, academic confidence, and academic performance.

Bandura's self-efficacy theory is a valuable framework for making sense of the differences in academic confidence among students who have failed mathematics. In following sections, this theory will be used as a theoretical framework to suggest a link between how students approach the engineering learning context and their academic confidence for mathematics and science.

6.1.3 *Expectancy-value Theory*

The final element of the theoretical framework is expectancy-value theory. Both expectancy-value theory and self-efficacy theory, which was described in the previous section, are theories of achievement motivation. Theories of achievement motivation attempt to explain an individual's choice of achievement tasks, persistence on these tasks, vigour in carrying out these tasks, and performance in these tasks (Wigfield, 1994; Wigfield & Eccles, 2000). Expectancy-value theory and self-efficacy theory bring a different perspective to the issue of students' motivation.

Expectancy-value theory has some overlapping constructs with self-efficacy theory such as ability beliefs, outcome expectations, and interests (Lent, Brown, & Hackett, 1994). However, expectancy-value theory places greater emphasis on the personal values, goals, and needs of individuals (Eccles, 2005). In its simplest form, expectancy-value theory suggests that choices to engage in activities, such as working in an engineering job, are mostly shaped by 'Tasks Value' beliefs. Whilst in contrast, self-efficacy theory is primarily concerned with somewhat dissimilar 'Competence' beliefs. Competence beliefs, address questions of ability, (i.e., "Can I do this task?") and Tasks Value beliefs consider the personal importance of a task, (i.e., "Do I want to do this task?"). Both of these beliefs could have an impact on the motivated goals and actions of students, as shown in Figure 6.2.

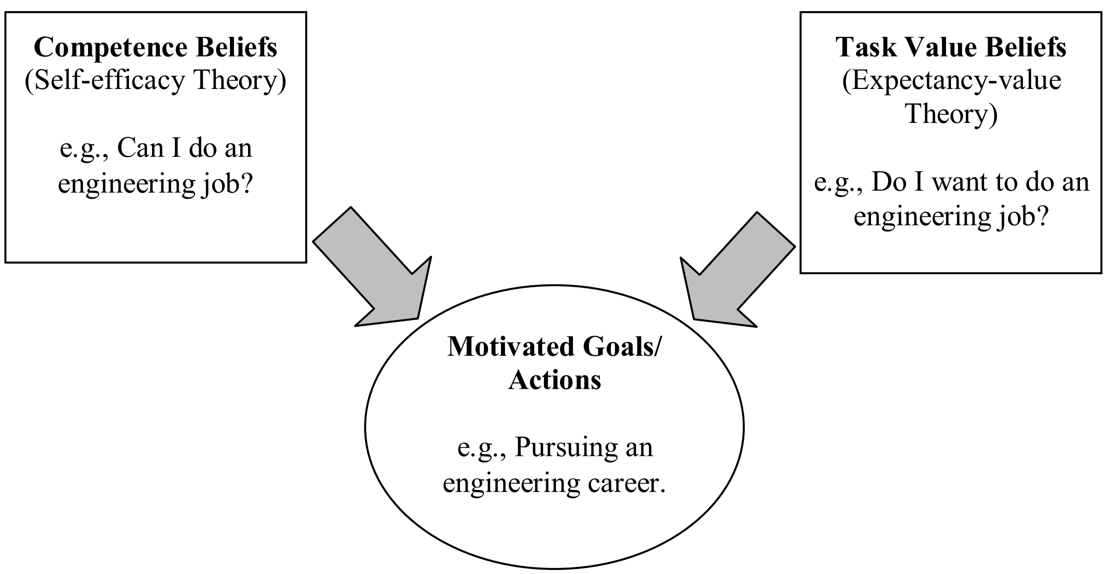


Figure 6.2 - Relationship between competency beliefs, task value beliefs and motivation to pursue an engineering career (adapted from Matusovich, Streveler, & Miller, 2010, p. 290)

Unlike competency beliefs, task value beliefs have been applied less widely in research of engineering education. Although, not many studies adopt an expectancy-value perspective to research tasks value beliefs, this area of research has recently emerged as important for understating engineering students' choices. The few studies that have studied tasks value beliefs in engineering, have shown promising results for increasing understanding of persistence in engineering as well as career choices (Li, McCoach, Swaminathan, & Tang, 2008; Matusovich, Streveler, Loshbaugh, Miller, & Olds, 2008; Matusovich, et al., 2010). Therefore, expectancy-value theory provides a proven framework to examine students' task value beliefs. Specifically, the beliefs that shaped their intentions to pursue an engineering career or pursue further engineering education after graduation.

Eccles et al. (1983) were one of the forerunners in applying expectancy-value theory to education. They proposed an expectancy-value model of achievement performance and choice, and studied it initially in the mathematics achievement domain. As mentioned earlier, while a self-efficacy model focuses on competency beliefs (i.e., a person's ability to do a task or engage in an activity) an expectancy-value model has a greater focus on task value beliefs (i.e., a person's desire to engage, or the importance of engaging, in a task or activity). Eccles et al. (2005; 1983) defined these subjective task value beliefs as the person's incentive for engaging in different tasks or activities based on both the nature of the task, and how well it aligns with personal values, goals, and needs.

Eccles (2005) and others (Wigfield & Eccles, 1992; Wigfield, Eccles, Schiefele, Roeser, & Davis-Kean, 2002), have identified four categories of task value beliefs. These are: (1)

attainment value (i.e., the individual's perception of how performance on the task matches with their self-concept); (2) intrinsic or interest value (i.e., the enjoyment experienced in doing the task); (3) utility value (i.e., the perceived future importance of engaging in the task that may be directly or indirectly related to the task itself); and, (4) relative cost (i.e., the price of success or failure in terms of effort, time, and/or psychological impact).

As mentioned earlier, the few studies that have adopted an expectancy-value perspective in engineering education have demonstrated the usefulness of this theory in increasing our understanding of persistence and career choice. Li et al. (2008) used the expectancy-value theory to develop an instrument that investigates differences between engineering and non-engineering students. They found that while both engineering and non-engineering students value the benefits of engineering, students in engineering exhibited higher intrinsic value and perceived a greater sense of social value for engineering. In applying expectancy-value theory to case studies from the longitudinal 'Academic Pathways Study', Matusovich et al. (2008) reported that the theory illuminated the ways in which students developed over time and how students were influenced by experiences both inside and outside of the classroom. They found that those students who lacked confidence in their engineering abilities could still somehow have a positive expectation for success.

In a recently concluded study on why students choose to study engineering, Matusovich et al. (2010) demonstrated that different patterns exist in the types of values that students assign to earning an engineering degree. The primary differentiating feature of these patterns was, whether or not participants chose engineering because it was consistent with their personal identity or sense of self. They also concluded that value beliefs were central to students' persisting in engineering, and that engineering educators should come up with ways to help students connect their personal identities to engineering identities. This resonates with the findings in Chapter 4, which identified 'Professional Persistence' after graduation as one of the key outcomes affected by prior mathematics performance. Expectancy-value theory provides a valuable framework for understating why students persist or not, as demonstrated by the studies by Matusovich et al (2008; 2010) and others.

In the followings sections, expectancy-value theory, together with self-efficacy theory and Ramsden's model of student learning in context, will be used to build a theoretical model that incorporates and explains some of the quantitative findings in Chapter 4 and the qualitative findings in Chapter 5. Comparing the findings from two sources in this fashion is also a form of triangulation that adds to the quality control measures for this study.

6.2 ***Triangulating the Quantitative and Qualitative Findings***

At this point in the thesis, it is necessary to revisit the quantitative findings from Chapter 4. The path models in this chapter, which have been built with quantitative data from 1217 students, show a generalisable pattern that can be used to infer the effects of prior mathematics failure on the educational outcomes throughout the institution. The path models showed that two important educational outcomes were, to some degree, directly and indirectly affected by prior mathematics failure (see Figure 4.5 on page 110 and Figure 4.6 on page 113). These educational outcomes were: (1) students' engineering knowledge, as measured their GPA; and, (2) students' desire to continue working or studying engineering after graduation. Of these two educational outcomes, the second one also known as Professional Persistence seemed to be more greatly affected by prior mathematics failure.

The current section focuses on Professional Persistence because of its strong association with prior mathematics performance in the quantitative findings, and its resonance with some of the qualitative findings. The quantitative analysis identified the intermediary psychological factors (of academic confidence and intrinsic motivation) that were affected by prior mathematics failure, which in turn led to lower Professional Persistence. However, the analysis did not provide an explanation of why these factors played a part in students' broader perceptions and experiences of learning engineering. The quantitative analysis only identified a causal relationship that involved these psychological factors, prior mathematics failure and Professional Persistence. This causal relationship is generalisable, and can be applied to the specific circumstances of engineering students who had previously failed GCE 'O' level Mathematics, as demonstrated by Figure 6.3.

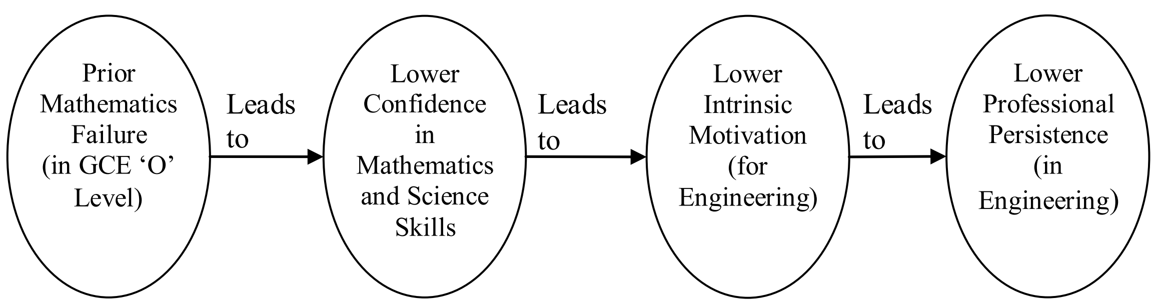


Figure 6.3 - How prior GCE 'O' level mathematics failure leads to lower Professional Persistence

This model while insightful, begs questions such as "Why does prior mathematics failure lead to lower academic confidence?"; "Why does lower academic confidence lead to lower intrinsic motivation?"; and, "Why does lower intrinsic motivation lead to lower Professional Persistence?" To answer these questions it is necessary to understand how students' perceptions of their experience of learning engineering are connected to these factors.

The qualitative findings in Chapter 5 shed light on the experience of learning engineering of nine student participants who had failed mathematics. It showed that conceptions of mathematics and engineering were at the heart of these students' learning experience. Students' conceptions were made up of their beliefs about and approaches to learning that subject. The qualitative findings showed that amongst most participants there was a strong overlap between their learning approaches in both mathematics and engineering. It also indicated that participants' conceptions of mathematics shaped their conceptions of engineering. The qualitative model constructed in Chapter 5 (see Figure 5.5 on page 173) shows this interconnected relationship between mathematics and engineering conceptions. The focus of this model, on students' conceptions, resonates strongly with 'Ramsden's Model of Student Learning in Context'. Like Ramsden's model, it shows that students' perceptions shape their approaches to learning, and are in turn shaped by the educational context and previous educational experience. This lends greater validity to the qualitative model, which was created using grounded theory methods. The model also alluded to the fact that Professional Persistence could be affected via student perceptions; by showing that beliefs about engineering knowledge that were formed while solving engineering problems, led participants to having certain expectations of the engineering profession. However, the model stopped short of making this connection between conceptions and Professional Persistence explicit.

The following sub-sections will establish the theoretical and empirical basis for this connection, and others, between the qualitative and quantitative models. In order to justify connections between the qualitative and quantitative models, it is necessary to rely on the theoretical framework established at the start of this chapter (see Section 6.1) and the qualitative interview data. The theories and models that have been discussed as part of the theoretical framework have been validated by numerous studies. They therefore form a sound basis for connecting related constructs in both models.

6.2.1 *Prior Educational Experiences are linked to Conceptions of Learning Mathematics*

Ramsden's model forms the basis of the first link between the quantitative and qualitative models. As mentioned earlier, Ramsden's work on students' perceptions of the learning context has been a significant influence on this study. In addition to validating the focus on student perceptions in the qualitative model, it makes it possible to link previous educational experiences to current perceptions of, and approaches to, learning. The connections in the visual representation of Ramsden's model may appear linear (see Figure 6.1); however Ramsden himself stressed that this diagram should not be taken to suggest a single causal sequence of events, but that the elements interact in a complex way with each other (Ramsden, 1992, p. 84).

What is known for sure, not only from Ramsden's work but also from similar work by Biggs (1989) and Entwistle (1998), is that there is a definite link from prior educational experiences to perceptions and approaches to learning. It is therefore reasonable to conclude that participants' experience of 'Prior Mathematics Failure' is linked to both their 'Beliefs about Mathematics' and 'Approaches to Learning Mathematics'.

Evidence for these links can be found in the participant quotes. The following extract from Andi's interview shows that his prior experiences with 'O' level mathematics affected his 'Beliefs about Mathematics' much more than his current experiences with mathematics in his engineering course.

> *Interviewer:* *What math have you done so far at the polytechnic?*
>
> *Andi:* *I think I did learn a bit of engineering math somehow or other. And some of the basic math actually helped me in my O levels because I took my O levels last year and it actually did help* ***[Approaches to Learning Mathematics]****.*
>
> *Interviewer:* *Has your perception of math changed because of this?*
>
> *Andi:* *Not really* ***[Prior Educational Experience]****. I think it's the same because mathematics is all about calculations and more calculations. Division, multiplication, sum, minus it's just about that.* ***[Beliefs about Mathematics]***

6.2.2 *Approaches to Learning are linked to Academic Confidence*

The second connection that can be theoretically established between the qualitative and quantitative constructs is between 'Approaches to Learning Mathematics', 'Approaches to Solving Engineering Problems' and 'Confidence in Mathematics and Science Skills'. The research literature reviewed earlier in this chapter (see Section 6.1.2), shows that self-efficacy beliefs are intimately associated with academic confidence. This correlation between self-efficacy beliefs and academic confidence has been observed both within engineering education (Vogt, 2008) and outside of it (Chemers, et al., 2001; Jimenez Soffa, 2007; Pajares, 2006). 'Mastery Experiences' and 'Social Comparisons' in particular have been shown to be the most influential sources of self-efficacy beliefs among engineering students (Hutchison-Green, et al., 2008; Hutchison, et al., 2006). The following student quotes show how the approaches adopted by students who have previously failed mathematics, led to lower academic confidence though failed mastery experiences and social comparisons.

Andi felt that because he had previously failed mathematics, a more directed approach to learning mathematics would suit him. The more "spoon fed" approach he would prefer to adopt is obviously not appropriate for PBL, and the desire to adopt this approach may have led to him being less academically confident. 'Mastery Experiences' with mathematics seem to be the main reason for Andi's lower academic confidence in the following quote.

> *I think so far I find it quite ok, but a bit hard for engineering for the math part. Because for me I failed my math right? So it's very hard for me to study PBL for math.* ***[Mastery Experiences]*** *It's not like being spoon-fed. You need to go*

> *do research yourself on the internet and find information in the worksheet and when you don't know the facilitator won't tell you* ***[Approach to Learning Mathematics]****. They will give you hints. Actually, it's not my type of learning.* ***[Low Academic Confidence]***

Diana too had low academic confidence and this seemed to influence the way that she approached solving engineering problems. However, unlike Andi, Diana's 'Social Comparisons' with her classmates seem to be the main competence belief that was related to her low academic confidence.

> *I still find difficulty in the calculation part and formulae, but usually if I do work in class I will try to contribute more with the theory* ***[Approach to Solving Engineering Problems]*** *because I am more theory based rather than calculations* ***[Low Academic Confidence]****. So I'm largely dependent on my classmates for calculation on how to do stuff.* ***[Social Comparisons]***

6.2.3 Beliefs and Expectations of Engineering are linked to Intrinsic Motivation

The final link between models can be theoretically established from 'Beliefs about Engineering Knowledge' and 'Expectations of the Engineering Profession' to 'Intrinsic Motivation (for Engineering)'. This connection relies on the previous research on expectancy-value theory. While self-efficacy has been shown to affect academic confidence and even student grades, research has found that simply because students have a high level of self-efficacy does not mean that they will plan to persist in engineering after graduation (Jones, et al., 2010). Theoretical evidence indicates that other factors, such as intrinsic or interest value (i.e., the enjoyment experienced in doing the task), may be more important determinants of students' intentions and choice of activities (Eccles, et al., 1983; Wigfield & Eccles, 2000). In addition a small but growing number of empirical studies have shown that expectancy-value related constructs can be used to predict professional persistence in engineering (Li, et al., 2008; Matusovich, et al., 2008; Matusovich, et al., 2010). (The literature that points to this connection was discussed in detail in Section 6.1.3.) Following is the suggestion from a student quote that certain beliefs about engineering knowledge and expectations of the engineering profession lead to having a lower intrinsic value and motivation for engineering.

When asked what she thought of working in the engineering profession in the future, Diana said she felt it was quite tedious because of the mathematics. From her words (below) it can be inferred that she beliefs that engineering knowledge is mostly mathematical in nature, and she expects to encounter more mathematics if she works in engineering.

> *Quite tedious, maybe because of the math. Because usually when one fails their math subject because of their disinterest in math* ***[Intrinsic Motivation/ Interest Value]****. So imagine you're already not very interested in math and then you are doing something every day that is related to math* ***[Expectation of the Engineering Profession/ Belief about Engineering Knowledge]*** *so you're probably thinking oh this math again and it gets very boring so it just makes you feel very tired and weary of doing all this mathematics.*

6.3 ***A Substantive Theory Incorporating the Major Findings of this Thesis***

The preceding sections have provided the theoretical rationale and empirical evidence for the connection between the qualitative and quantitative findings in this study. While the qualitative findings focused on the in-depth perceptions of students' experiences of learning engineering, the quantitative findings focused on generalisable trends across the institution. Bringing together the qualitative and quantitative findings in this way increased the credibility of the overall findings, and leads to a more robust understanding of the research problem than either approach alone. It also forms the basis for a theoretical explanation of the situation being researched, which is a goal of this study. This type of explanation that is grounded in one particular research area is called a substantive theory and is described as "plausible relationships proposed among concepts and sets of concepts" by Strauss and Corbin (1994, p. 277). Strauss and Corbin make a distinction between substantive theory, which is grounded in one particular research area, and formal (higher order) theory, which derives from a variety of contexts. They also state a preference for "conceptually dense" theories, which are theories comprising many conceptual relationships that uncover patterns and identify processes.

Figure 6.4 visually represents the main concepts from the qualitative and quantitative findings and the theoretical links between each. From the evidence presented earlier, these links seem to be bidirectional in nature and have been represented as dotted bidirectional arrows. This model can be considered a summary of all the main research findings and can be thought of as the substantive theory, of how students who complete an engineering diploma within this context are affected by a prior mathematics failure.

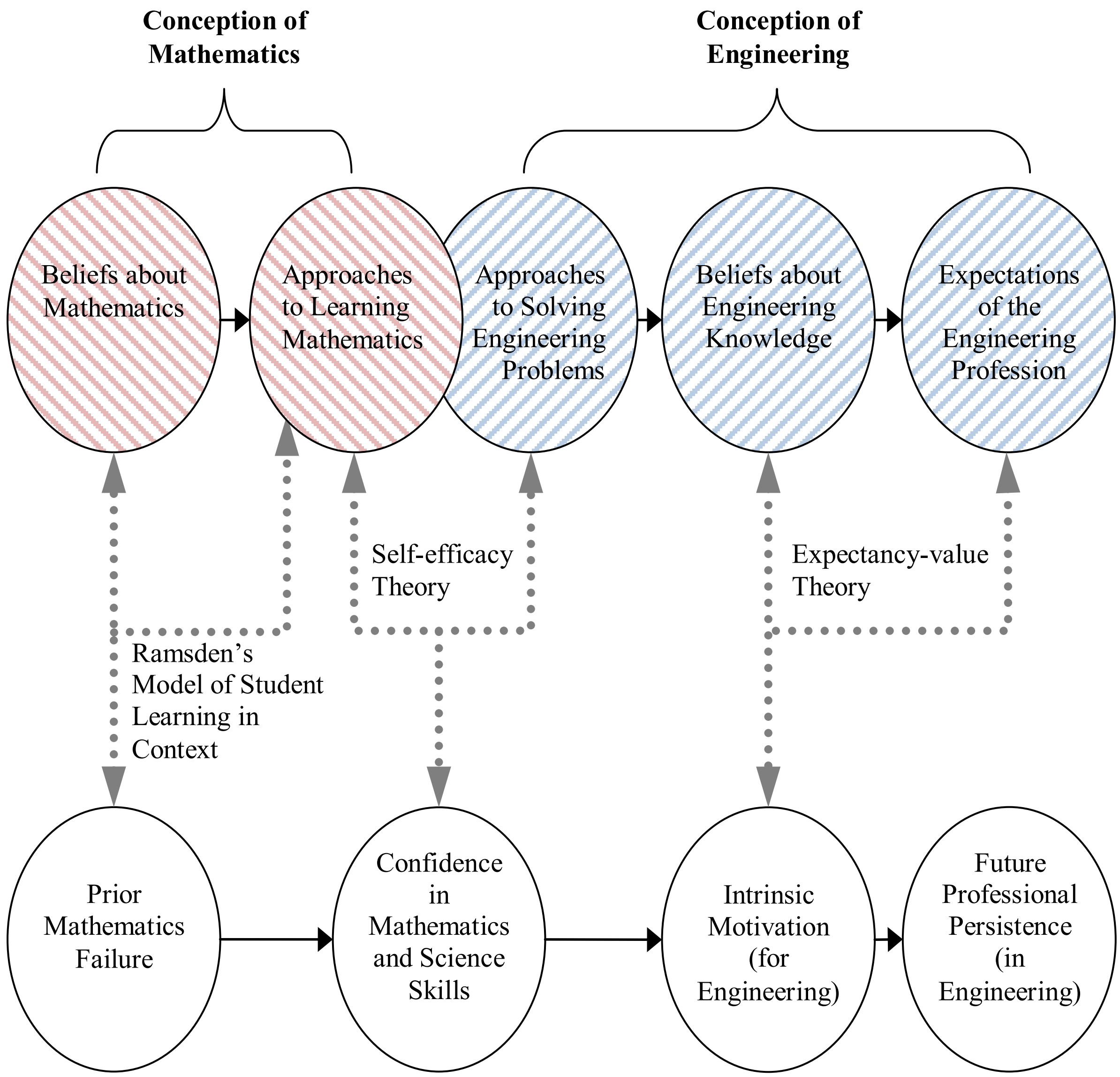


Figure 6.4 - Model of how students who complete an engineering diploma in this context are affected by a prior mathematics failure.

6.4 ***Differences in Individual Conceptions of Engineering***

The model on the previous page illustrates the general pattern that was observed with most of the student participants. Overall, the participants had low academic confidence and did not express much motivation for learning engineering, though some of them did feel that engineering careers could be intrinsically rewarding. Participants held a broad range of conceptions, including both higher and lower order beliefs, on the nature of mathematics and engineering. However, most of them could not express a clear distinction between their conceptions of engineering and their conceptions of mathematics, during the interviews. In addition, the model indicates that it would be unlikely that the majority of them want to persist in engineering after graduation. Based on the theoretical literature, students' conceptualisation of various subject domains, together with their self-efficacy related beliefs and their expectancy-value related beliefs, provided the best explanation for this observed pattern.

Cai was the most obvious and intriguing exception to this general pattern. Despite having initially failed 'O' Level mathematics and having taken a longer route to reach the polytechnic than all of the other participants, he graduated in 2010 as one of the top performers of his entire cohort. Throughout his interviews, he expressed higher levels of academic confidence and intrinsic motivation than other participants. When asked what he thought about his current engineering ability, he said:

> *I think it might have improved a lot over the last year. I realise now that I do like solving engineering problems* ***[High Intrinsic Motivation]*** *and actually, I'm quite sure of applying what I know now* ***[High Academic Confidence]***.

However, what was most telling from his interviews was that he had, by far, the most well developed conception of engineering, as compared to the other participants. Most of whom, were not able make much of a distinction between portions of mathematics and engineering. When asked the question, "How is mathematics and engineering different?" Cai's response was:

> *Engineering is about application of the math, while math is just a tool. Nothing but a tool. So the tool is only as good as how you use it. It's about making sense of the numbers while engineering uses this mathematics to what we need to apply. Let's say I need to calculate the safest load I can have for the lift. If I don't know basic math, any math at all, I wouldn't be able to do that. You could do it by trial and error, but it's quite dangerous, with human life at stake.*

Further analysis of the interview transcripts and researcher memos, suggested that different participants' conceptions of engineering were at various levels of distinction from their conceptions of mathematics. Cai's conception of engineering was clearly distinct from his conception of mathematics. Contrary to this were three participants who did not make any meaningful distinction between these subject domains other than to express the belief that engineering knowledge involved more "hands-on" skills (see Table 5.3 Beliefs about what counts as engineering knowledge). Two of these participants, Vick and Tamir, even indicated during their interviews that they did not have an idea of what to expect of engineering careers and studies in future. However, the bulk of the participants did seem to have some impression of what to expect and their conceptions of engineering appeared somewhat distinct; though the overlap with mathematics was still considerable.

Table 6.1 following, summarises how distinct each student's conception of engineering was, from their conception of mathematics.

Table 6.1

Summary of the distinctiveness of individual students' Conception of Engineering from their Conception of Mathematics

	Not Distinct	**Somewhat Distinct**	**Clearly Distinct**
Vick	✓		
Tamir	✓		
Diana	✓		
Andi		✓	
Fizal		✓	
Rachel		✓	
John		✓	
Lan		✓	
Cai			✓

It is hard to positively determine whether the cause of Cai standing out from the other participants was his mature age, his unique prior experiences, learning style or just because of his resilient personality. Nevertheless, the qualitative differences in both his experience of learning engineering and his educational outcomes were clear from the data. Cai's situation seems to indicate that the pattern described by Figure 6.4 (on page 199) can be broken. Perhaps this can be achieved by doing something as benign as helping students to make a clear distinction between the domains of mathematics and engineering.

6.5 ***Summary of the Overall Findings***

Research on the student experience is fundamental in shaping how engineering education will evolve. Furthermore, looking at students' experiences broadly entails not just thinking about what they learn (i.e., technical and professional skills and knowledge) but also their motivation, their identification with engineering, their academic confidence, and their choices after graduation. The participants' experiences of learning engineering in this study are as diverse as the participants themselves, and differences in how they conceived of engineering may play out in a variety of ways. What is clear is that these students' conceptions of engineering as a field of study and a profession are intimately tied to their academic confidence and motivation to become engineers. The findings have established that students who have failed mathematics in the past can still be haunted by this failure while learning engineering. Prior failure in mathematics, even if it did not directly lead to poorer grades, seemed to influence the type of conceptions of engineering that they had.

This chapter, and previous ones, have reviewed a number of studies that investigated the experience of learning engineering, and demonstrated that motivation, confidence and conceptions of engineering are important issues. The final report of the U.S. National Science Foundation funded Academic Pathways Study, published in June 2010, also reiterates the importance of these issues in learning engineering (Atman et al., 2010). In concordance with the findings presented in this thesis, the Academic Pathways Study found an association between confidence in mathematics and science, intrinsic motivation and professional persistence (pp. 23 & 43) and echoed the importance of conceptions of engineering in affecting confidence in engineering (p. 47). This study, and others, has shown that some of these factors have more influence with one demographic group than another. However, they have mostly focused on demographic groups that were defined by gender, age, socioeconomic status and year of study.

Educational experience has also been acknowledged as an important determinant of the educational experience and has been studied to some extent. However, none of the studies encountered focused specifically on a demographic group defined by prior mathematics failure as in this PhD study. The understanding of this group of engineering students' experiences could serve as inspiration for designing innovative curricular experiences that support these students on their way to becoming an engineer.

Chapter 7 Conclusion

The detailed findings of this study have been presented in the preceding chapters (Chapters 4, 5 and 6), in the form of tables and models. This final chapter seeks to highlight the contributions of this thesis, by showing how each research question has been addressed and by summarising the most significant research findings. It also discusses the implications of these contributions, both for teaching engineering and for helping engineering students further develop their conceptualisation of engineering. Finally, this chapter appraises the research methodology employed in this study, and concludes with a discussion of the limitations of the research and suggestions for future work.

7.1 ***Contributions***

This study set out to explore the impact of prior mathematics performance on the experience of learning engineering in a Problem-Based Learning (PBL) setting. It investigated students' experiences of learning engineering, within the context of a unique one problem per day approach to PBL at a polytechnic. It achieved this by examining both the broad perspectives of students across the institution and the in-depth perspectives of students who had failed mathematics. To elicit these two different types of perspectives, this study made use of both a validated survey instrument and one-to-one interviews respectively. There were 1217 valid responses to the survey, and nine students who previously failed mathematics participated in the interviews. The data generated from both of these sources were analysed by two different means. The survey data were analysed using quantitative methods and the interview data were analysed using quantitative, grounded theory methods. Both of these analyses led to complementary findings that explained various facets of the students' experience of learning engineering. For the sake of clarity, these findings were presented as a series of tables and models. Finally, selected quantitative and qualitative findings were brought together based on formal educational theory and evidence from the interviews. That step helped to triangulate the findings, and to achieve a more in-depth understanding of the educational experiences of the students' who had previously failed mathematics (that were participants in this study).

The research process described above was guided by four research questions and resulted in tangible contributions to the field of engineering education. The following sections review how the research questions have been answered and summarise the major findings and contributions of this study.

7.1.1 *Review of the Research Questions*

There were four main research questions. The first research question was primarily addressed by the quantitative findings, while the remaining three research questions were primarily addressed by the qualitative findings. In addition to guiding the study, the four research questions led to the development of a substantive theory, which proposed how students who complete an engineering diploma are affected by a prior mathematics failure. This substantive theory was discussed in detail in the previous chapter (Chapter 6). In the current section, each research question is discussed individually and the answer to each question is reviewed, to help make the case that all of the research questions have been adequately addressed.

A. Research Question 1

The first research question was:

What are the important factors and outcomes associated with learning engineering in a dedicated Problem-Based Learning (PBL) setting; and how does prior GCE 'O' Level mathematics performance affect these factors and outcomes?

This question was addressed in Chapter 4 using both the student demographic information and the results of the institution wide survey, which broadly measured 24 constructs related to engineering education. The question was answered in two parts. The first part of the chapter focused on identifying the important factors associated with the students' experiences of learning engineering. The cross-sectional data from the survey allowed factors to be selected by: (1) the way that students rated them; (2) their association with demographic factors of interest; and, (3) how they changed from year to year. These factors and the reasons they were considered important in this study are summarised in Table 7.1 on the following page.

Table 7.1

List of Important Factors Associated with the Students' Experiences of Learning Engineering

Factor	**Reason Considered Important**
Professional Persistence	- Was moderate - Decreased moderately from year to year
Perceived Importance of Mathematics and Science Skills	- Was high - Was higher than professional and interpersonal skills - Did not seem to change year to year
Confidence in Mathematics and Science Skills	- Was moderate - Did not seem to change year to year - Was lower than confidence in professional and interpersonal skills, and solving open-ended problems - Correlated strongly with prior mathematics performance
Intrinsic Motivation	- All the measures related to intrinsic motivation were low to moderate - These measures decreased moderately from year to year
Exposure to the Engineering Profession	- Was low - Did not seem to change year to year
Involvement in Engineering Related Activities	- Was low - Did not seem to change year to year
Academic Disengagement (Engineering-related Courses)	- Was low - Increased moderately when students encountered engineering related subjects in the 2nd and 3rd years - Had the strongest correlation with student GPA

The second part of Chapter 4 focused on answering how prior mathematics performance was, both directly and indirectly, related to these important factors. It did so by building and testing path models that hypothesised the relationships between these factors.

Models were built which explained 21% of the variation in student GPA and 29% of the variation in Professional Persistence. The models helped to determine that while prior mathematics performance has an effect on GPA, its direct effects were small compared to other factors. One of the path models that were built showed that prior mathematics performance affected Professional Persistence through the mitigating factors of Confidence in Mathematics and Science Skills, and Intrinsic Motivation. This model resonated with the qualitative findings that addressed research questions 2, 3 and 4. Hence, the answers to the first research question were elucidated through the process of identifying important factors and building models that related these factors to each other.

B. Research Question 2

The remaining research questions (2, 3 and 4) were addressed by the qualitative findings from the interview data. These findings were presented and discussed in detail in Chapter 5. The second research question can be expressed as follows:

What do students, who have previously failed the GCE 'O' Level mathematics, believe about the mathematics they have learnt; and how do they approach mathematics in the context of engineering education?

The answers to the first research question guided the data collection and analysis that helped to answer the second research question. However, unlike the first research question (which is concerned with the factors that are associated with learning across the entire institution), the second question is concerned with the meaning that students who failed mathematics ascribe to mathematics, and their approaches to learning the subject. To answer this question nine students, who were in the unique situation of having previously failed mathematics were interviewed. The interviews were transcribed and the transcripts were analysed using grounded theory methods.

The findings were in the form of codes, which described two distinct themes associated with learning mathematics. These two themes were the students' various beliefs about mathematics and their approaches to learning mathematics. The literature was only consulted a posteriori in order to interpret these codes and guide further data collection. It was found that these students predominantly had surface beliefs about mathematics, and had surface and procedural approaches to learning mathematics. A complete list of the codes associated with mathematics, and a detailed description of each code can be found in Section 5.2, in Chapter 5.

C. Research Question 3

The third research question was:

What are these students' beliefs about engineering knowledge; how do they approach engineering problems in a dedicated PBL setting; and what are their expectations of the engineering profession?

Like the second question, this question was answered by analysing the qualitative interview data from nine participants and the findings relating to this question are in the form of codes. While Research Question 2 focused on conceptions related to mathematics, Research Question 3 was primarily concerned with conceptions related to engineering.

The codes generated were grouped into three themes: (1) beliefs about engineering knowledge; (2) approaches to solving engineering problems; and, (3) expectations of the engineering profession. Four distinct beliefs about engineering knowledge were identified. The predominant belief was that it involved acquiring technical skills through doing some task. Overall, the participants' beliefs about engineering knowledge were not very sophisticated. There were three codes associated with the ways that participants approached engineering problem solving and the approaches seemed to be mostly procedural in nature. Finally, four codes describing expectations of the engineering profession were identified. Most participants struggled to express anything substantial about the engineering profession; however, one participant stood out from the rest as he was prolific in expressing his perspectives of the profession. A detailed description of the codes and themes associated with engineering can be found in Section 5.3, in Chapter 5.

D. <u>Research Question 4</u>

The final research question was:

What is the grounded explanation for these students' experience of learning engineering; and how does this experience affect the educational processes and outcomes of these students?

This question builds upon the earlier three questions, but is at a higher level of generality. Its emphasis is on the relationships between the five themes that were identified by answering Research Questions 2 and 3. In order to answer this question, models were built with evidence from the interview data and the engineering education literature. The details of how these models were built can be found in Section 5.4, in Chapter 5.

The evidence indicated that the participants' prior experiences with mathematics shaped their beliefs about mathematics, which in turn affected their approaches to learning mathematics. It also seemed that there was a significant overlap in the participants' approaches to learning mathematics and their approaches to solving engineering problems. Participants indicated that they used similar approaches for both mathematics and engineering. In regards to the themes related to engineering, the data indicated that the approaches used to solve engineering problems affected beliefs about engineering knowledge. Furthermore, participants' beliefs about engineering knowledge seemed to be strongly associated with their expectations of the engineering profession. Figure 5.5 (on page 173) is a visual representation of the relationships between these themes.

7.1.2 *Summary of the Major Findings of this Study*

The purpose of this section is to reiterate selected findings that have the most potential to make a significant contribution, to both the educational literature and educational practice.

A. List of Themes

One such contribution is, a "List of Themes" that label ways in which the engineering students in this study conceptualised mathematics and engineering. These themes are related to either epistemological beliefs or learning behaviours. Each theme is also associated with a number of codes. The codes define the various ways in which that theme was expressed during the interviews. The themes and codes that make up this list were described in detail in various sections in Chapter 5. This list is summarised in Table 7.2 on the following page, and includes a column stating the prevalence of each code among the interview participants.

Table 7.2

List of Themes: Representing ways that mathematics and engineering were conceptualised, and their prevalence among the participants in this study

	Theme	Code	Prevalence
Epistemological Beliefs	Beliefs about Mathematics	- Formulaic	High
		- A Tool	Medium
		- A Form of Thinking	Low
		- Not Useful	Medium
		- Useful	Medium
	Beliefs about Engineering Knowledge	- Completing a List of Engineering Topics	Medium
		- Applying Formulas to Solve Problems	Medium
		- Acquiring Technical "Hands-On" Skills	High
		- Understanding Scientific Concepts	Low
	Expectations of the Engineering Profession	- Involves Teamwork	Low
		- Understands Technology	Medium
		- Solves Authentic Problems	Medium
		- Is Intrinsically Rewarding	Medium
Learning Behaviours	Approaches to Learning Mathematics	- Listen and Remember	Low
		- Practice by Themselves	Medium
		- Ask Knowledgeable Peers	Low
		- Analyse Worked Examples	Low
		- Just Apply Right the Formula	Medium
	Approaches to Solving Engineering Problems	- Start With What They Know	High
		- Analyse Worked Examples	Medium
		- Just Apply the Right Formula	Medium

This "List of Themes" could potentially be used as a resource for engineering educators for designing educational activities. This list might also be used as the basis for creating a perception of engineering survey, which could be useful for career counselling prior to admission into the polytechnic. The 'Implications' section (Section 7.2) later in this chapter discusses these and other implications in greater detail.

B. <u>Substantive Theory and Theoretical Framework</u>

Another contribution of this study is the substantive theory developed in the previous chapter and presented in Chapter 6 (see Figure 6.4 on page 199). This theory can be thought of as an explanation of how students in the context of this study are affected by their prior mathematics failure, while studying for an engineering diploma. This theory proposes, that prior mathematics failure could have unobserved effects on how students form conceptions of mathematics and engineering. Moreover, these conceptions are linked to students' academic confidence and intrinsic motivation. The substantive theory suggests that professional persistence in engineering is an educational outcome that could be adversely affected by the interaction of these influences on learning. The theory also indicates that student conceptions of mathematics and engineering play a central role in the experience of learning engineering, and that engineering educators should pay more attention to how these conceptions come about.

In order to formulate this theory, a theoretical framework was proposed that brought together and applied three well-established theories from the fields of educational psychology and educational research (see Section 6.1). These three theories were: (1)

'Ramsden's Model of Student Learning in Context'; (2) 'Self-efficacy Theory'; and, (3) 'Expectancy-value Theory'. This theoretical framework was needed to explain the interaction between the various themes and factors, which were identified earlier in the study. A proposed theoretical framework and its application can be considered a significant contribution in itself, as it "outlines the project's potential contribution to knowledge by describing how it fits into theoretical traditions in the social sciences or applied fields in ways that will be new, insightful, or creative" (Marshall & Rossman, 2006, p. 71). In this study, the theoretical framework was used to establish or reinforce links (↔) between the following pairs of constructs which are relevant to engineering education:

- Prior Educational Experiences ↔ Conceptions of Learning Mathematics
- Approaches to Learning ↔ Academic Confidence
- Beliefs and Expectations of Engineering ↔ Intrinsic Motivation (for Engineering)

Therefore, in addition to the substantive theory another important contribution of this study is the coherent theoretical framework that was proposed. This framework integrates closely related educational theories to suggest novel links between important constructs in engineering education. The substantive theory allows for new ways of thinking about the learning experiences of engineering students within the context of the study, and the theoretical framework can be applied to investigate other similar contexts. The implications of these findings and contributions will be discussed more in the subsequent section.

7.2 ***Implications***

The results of this study offer some thought-provoking implications; both for teaching engineering well and for helping engineering students persist in the engineering profession. This section discusses these implications and makes recommendations to readers who are involved in engineering education.

7.2.1 *General Implications for Engineering Education*

This section discusses the general implications of this study, as related to both the everyday educational practices in engineering and to the building of theoretical knowledge in engineering education.

A. Expansion of the Theoretical Foundations for Investigating the Effect of Prior Academic Performance

Marshall and Rossman in their book "Designing Qualitative Research" (2006), state that "the development of theory takes place by incremental advances and small contributions to knowledge through well-conceptualised and well-conducted research" (p. 71) and that "creative research can emerge when a researcher breaks theoretical boundaries and reconceptualises a problem or relocates the problem area" (p. 71). Arguably, the current study reconceptualised the problem of poor prior mathematics performance of engineering students, and studied its effects on the processes and outcomes of engineering education in a novel way.

The current study makes the case that the theoretical foundations used to investigate the effects of poor mathematics performance should be expanded to include student conceptions of mathematics and engineering. Psychological theories could be utilised to account for the relationships between these student conceptions, and their academic confidence and intrinsic motivation. In the context of this study, the theories of Self-efficacy and Expectancy-value offered worthwhile theoretical perspectives, to answer the question of how having certain conceptions of engineering can affect these psychological constructs. What was unique about the application of these theories here was that the Self-efficacy and Expectancy-value theories of motivation were linked to different constructs. This helps to make the case that both theories are useful in these types of studies. Many studies in engineering education have typically adopted one of these theories over another (see Hutchison-Green, et al., 2008; and, Li, et al., 2008), though of late some studies have recognised the legitimacy of using both of these theories together (see Jones, et al., 2010).

The engineering industry measures an engineer’s worth from his or her breadth and depth of disciplinary knowledge, as well as his or her personal and professional skills, ability to work with other engineers and with colleagues from other disciplines (Crawley, et al., 2007). Institutions of engineering education have been focused on developing engineering graduates with these attributes, but this effort could be wasted if despite developing these attributes, engineering graduates do not see themselves as future engineers. The findings of this study validate the idea that the psychological outcomes of engineering education (such as professional persistence and developing an engineering identity) should be considered along with the cognitive outcomes (like knowledge and skills development).

B. Reassessment of the Mathematics Education of Engineering Student

Another of this study's implications for engineering educators is to rethink strategies, for both teaching mathematics to engineering students and for integrating mathematics into engineering curriculum. This study has shown that students learn more than just mathematical skills and knowledge in their mathematics courses. They are likely to develop certain conceptions of mathematics because of these courses, and these conceptions of mathematics may influence their future approaches to and beliefs about engineering.

While mathematical skills and knowledge certainly are important to pass engineering courses (Budny, et al., 1997; LeBold, et al., 1989), engineering schools tend to overemphasize the importance of mathematics in solving real life engineering problems (Chisholm, 2003; Glass, 2000; Reed, 2001). One need only to refer to Hills and Tedford's (2003) model of the Virtuous Cycle of Learning (see Figure 2.1 on page 47), to understand the importance of integrating mathematics properly into the engineering curriculum. Hills and Tedford claim that an engineering student may encounter 20 or more of such cycles of learning, and the most common cause of demotivation is a failure to transfer knowledge in one or more cycles of mathematics.

The findings of this study suggest that, at least for mathematically weak students, a more deliberate effort must be made to design curriculum that shows students how mathematics is really applied in engineering problem solving. This could help them to overcome the motivational hurdle indicated by both this study and the Hills and Tedford (2003) model.

To think of mathematics in this way, some engineering educators may have to come to terms with the idea that it is more important for engineering students to understand what engineering is than to develop mathematical competencies. Particularly, if one of their goals is to train engineering graduates who will stay in the field. This study adds to calls from other engineering educators (Fuller & Jorgensen, 2004) for a major reassessment of the mathematics education of engineering students to ensure that the mathematics education provided for engineering students is congruent with modern engineering practice and industry needs.

7.2.2 *Specific Implications for the Institution*

In this section, the specific implications for the polytechnic where this study was conducted are discussed along with explicit suggestions for the policy makers and educators there.

A. Considering Students' Conceptions of Engineering in Enrolment Decisions

Because it is the newest polytechnic in Singapore, the institution were this study was conducted finds itself in the unique position of having to enrol a relatively large number of students who had failed O-level mathematics in engineering programmes, (over 100 students in some years). Enrolment decisions on these students are made solely on the basis of their performance in other subjects, such as science or language subjects. This study shows that their academic confidence and the intrinsic motivation for engineering are also important factors to consider. Their conceptions of mathematics and engineering should also be determined in order to better counsel students on what to expect from their engineering courses. The following are some suggestions about how to use the findings from this study to enhance enrolment decisions:

1) Applicants to the polytechnic, who have failed mathematics, could be required to participate in an activity where they have to solve a simple engineering-type problem. While engaged in this problem solving activity they could be observed by engineering faculty, with the purpose of determining their level of academic confidence and intrinsic motivation to do engineering. While this suggestion may put additional stress on applicants, it would give students who are able to benefit most from the engineering course the opportunity to enrol.
2) The list of qualitative themes from this study (see Table 7.2) could be used as a basis for an open-ended questionnaire designed to encourage applicants to reflect on and share their conceptions of engineering. Based on their responses, engineering faculty could advise them about their potential misconceptions about engineering. This has the added benefit of 'convincing' students who may not have otherwise considered engineering courses to apply.

B. Early and Active Exposure of Students to the Engineering Profession

Some of the immediately relevant findings from this study were that: students reported low exposure to the engineering profession; low involvement in the engineering related activities outside class; and, only moderate knowledge of the engineering profession. When taken together with the substantive theory that indicated that conceptions of engineering were central to the learning experience, that implied that more needed to be done to expose students to real engineering problems and the engineering profession.

Ideally, such exposure would be early in the engineering curriculum and involve the active engagement of the students. The following are a few specific ideas for ways to increase students' knowledge of engineering and help them develop an identity as future engineers:

1) Starting with the first-year students, offer opportunities for students to interact with engineering faculty. This is especially important in the first-year as students are enrolled in foundational mathematics and science courses taught by other departments. Waiting for the second-year to expose students to engineering may be too late, as their perceptions already start to form while enrolled in subjects like mathematics.
2) Develop interaction opportunities like a final-year project exhibition, where final-year students can display their projects to first-year students and applicants, as they have likely had little exposure to such projects. It could serve as a recruiting tool with the dual benefit of getting students to think about their final-year project ahead of time.
3) The professional profiling course run at the end of the second-year, where students have to profile an engineering related topic should be moved to the end of the first-year to allow earlier exposure to engineering. A compulsory industrial orientation or internship should be run at the end of the second-year or in the middle of the third-year. At this point students should have learnt enough to observe and make sense of some real life engineering problems.

7.3 ***Limitations***

While this study has immediate implications for both the wider education community and the polytechnic where this study was conducted, the findings must be interpreted within the context of its limitations. Some of the limitations of this study are the generalisability of the findings and the trade-offs of adopting a cross-sectional study design.

7.3.1 *Generalisability of the Findings*

This study sampled broadly from across the entire engineering student population at the polytechnic described in Chapter 1 (Section 1.2). However, the population of the study was limited to this one large institution where the approach to teaching and learning was consistently PBL. This limits the generalisability of the results outside the polytechnic on a number of fronts. Firstly, it is possible that unseen aspects of the educational culture may be influencing the experience of learning engineering at this polytechnic, and students in other polytechnics may have a different experience. Secondly, it is hard to account for the influence of PBL on the experience of learning because there is no basis for comparison with students who do not experience PBL, within the current study design. Both of these limitations can only be overcome by adopting a multi-site study design - which was beyond the scope of the current research project.

A third issue is associated with the generalisability of the insights from only nine students, from the qualitative portion of the study. This small number of students is an inherent trade-off of using qualitative methods for a portion of this study. However, Lincoln and Guba (1985) suggest that this type of research should not be judged by how generalisable its results are, rather it should be judged on how transferable and fitting its results are to each particular context. Nonetheless, the rich insights from this portion of the study can be used as foundations for future studies, which do aim to produce generalisable results.

7.3.2 *Limitations of a Cross-Sectional Study Design*

Another limitation associated with the choice of study design, is that both the quantitative and qualitative aspects of this study were cross-sectional instead of longitudinal. Therefore, in many ways, this study is but a snapshot of the students' experiences and there was no scope for investigating the following issues. Firstly, how student conceptions of engineering and mathematics changed with time. Secondly, how these changing conceptions related to specific learning instances in PBL, which may affect confidence and motivation during their three-year course. Thirdly, how changes in confidence and motivation due to students' transition to a workplace setting affected their conceptions of engineering and mathematics.

There is good reason to believe that the process of transitioning through various stages of study and to work will affect these factors, as research has shown that beliefs about engineering knowledge, the role of mathematics and career plans change drastically in this transition (Stiwne & Jungert, 2010). These limitations can also be the basis for future studies into the experience of learning engineering as discussed in the next section.

7.4 ***Future Work***

The current study offered several important insights into how a prior failure in mathematics could affect students' experiences of learning engineering. It highlighted the importance of the interconnection between student conceptions of mathematics and engineering; and the influence of these conceptions on academic confidence, intrinsic motivation and professional persistence. However, continued study is needed to further validate these connections and uncover further insights. Some of the potential areas for future study include: (1) a longitudinal multi-site expansion of the current study; (2) building dynamic models of the students' learning experiences that show how various factors change with time; and, (3) continued study of students' actual academic and professional persistence.

7.4.1 *Longitudinal and Multi-Site Study*

As mentioned in Section 7.3, limitations of the current study are its restricted generalisability and the extent to which it could explore how various factors changed with time. Therefore, a multi-site expansion of the current study that tracked participants from enrolment to a few years after graduation is a worthy future consideration. For such a future study, a survey instrument could be developed based on the codes, themes and factors identified in the current study (see Table 7.1 and Table 7.2). This survey instrument could be administered repeatedly to engineering students enrolled at various polytechnics. Participants, whose responses changed significantly from one survey to the next could then be interviewed to ascertain the reasons for those changes. That type of study would enhance the external validity of the findings and it would help identify key events which influence the career paths that engineering students take.

In order to maximise the external validity of such a future study, students with different backgrounds from various institutions with varying structures should be included. The study should include:

1) Students who took different paths prior to enrolment in the polytechnic, such as students who have completed an ITE certificate and international students
2) Polytechnics that adopt different pedagogical structures, including schools where teaching is conducted primarily through didactic or student-centred means
3) Students enrolled in a broad spectrum of types of engineering programmes, including programmes in chemical engineering, mechanical engineering and civil engineering which were not included in the current study

7.4.2 *Academic and Professional Persistence*

Professional Persistence emerged as an important issue that was related to students' confidence, motivation and conceptions of the field. In this study, there were two distinct measures of persistence, Professional Persistence and Academic Persistence. Academic Persistence is basically a measure of a student's intention to complete his or her engineering diploma. While Professional Persistence was discussed at length in this thesis, Academic Persistence was largely disregarded because almost all the students who responded to the survey replied that they strongly intended to complete their diploma programme. There is a possibility that this self-rating of persistence may be inflated, as it was based on a single question in the survey. Previously, other studies have indicated that students' intention to persist in engineering education could be underpinned by their beliefs about engineering, their sense of belonging in engineering and their identity as future engineers (Lichtenstein, Loshbaugh, Claar, Bailey, & Sheppard, 2007; Seymour & Hewitt, 1997). These issues are related to the findings in the current study, therefore Academic Persistence deserves further investigation. In a future study, Academic Persistence could be confirmed by observations by engineering educators in order to differentiate students who demonstrate high and low persistence.

In a similar vein, the measure of Professional Persistence in this study was in reality a self-reported intention to persist in engineering after graduation, as opposed to actual persistence after graduation. As suggested earlier, a longitudinal study of engineering graduates that looks at the paths students have taken since graduation and their reasons for persisting with certain paths, would be a significant contribution to the literature. Initial work in this area has been done by the Academic Pathways Study (Sheppard, et al., 2010) in a U.S. context. However, the literature is devoid of such studies within an Australasian context. If such a study is conducted in the future, it should focus on the experiences of engineering students and graduates who are typically thought to be less likely to persist in the field, such as women (Gill, Sharp, Mills, & Franzway, 2008), minorities and needy students (Fenske, Porter, & DuBrock, 2000), and poor academic performers.

7.4.3 *Dynamic Models of the Learning Experience*

It was suggested earlier, that future studies should track how various factors associated with the learning experience changed with time. Models are a good way to visualise and build theory that explains the ubiquitous interactions between factors associated with the students, their learning context and the curriculum. Conceptual and causal models are well established in educational research (Anderson & Evans, 1974; Von Glaserfeld & Steffe, 1991), but if the goal is to understand how learning takes place, educational models need to be built that reflect the complex and changing nature of learning in the classroom (Jacobson & Wilensky, 2006).

One approach that is often used in engineering to model complex changing systems is called Systems Dynamics. In this approach, models with feedback loops are built iteratively, with each iteration leading to better and more robust models. Luna-Reyes and Andersen (2003) advocate that a System Dynamics approach is suitable for modelling complex systems found in the social sciences, and that both qualitative and quantitative data may be used to create these models. They suggested that even though building such models takes time and effort, it could lead to models that explain critical dynamic data. A key feature of dynamic models that differentiate them from linear models is a focus on identifying causal loops (feedback loops). These loops are important as they may be balancing causal loops (leading to the plateauing of certain factors), or they may be reinforcing causal loops (leading to the exponential increase or decrease of certain factors). To illustrate this idea, a dynamic model has been proposed in Figure 7.1, based on selected findings from the current study.

There are two reinforcing causal loops in this initial model. Firstly, a "Virtuous Cycle of Encouragement" that increases academic confidence and intrinsic motivation, and is associated with conceptions of engineering that are distinct from mathematics. Secondly, a "Viscous Cycle of Discouragement" that decreases academic confidence and intrinsic motivation, and is associated with conceptions of engineering that are similar to mathematics. This model theorises that as students acquire certain conceptions of engineering, there is a predictable change in their academic confidence and intrinsic motivation. In future research, this prediction could be measured and tested, and this model could be iteratively improved based on the results. This and other novel techniques used in engineering have the potential to revolutionise engineering education, if creatively and appropriately applied.

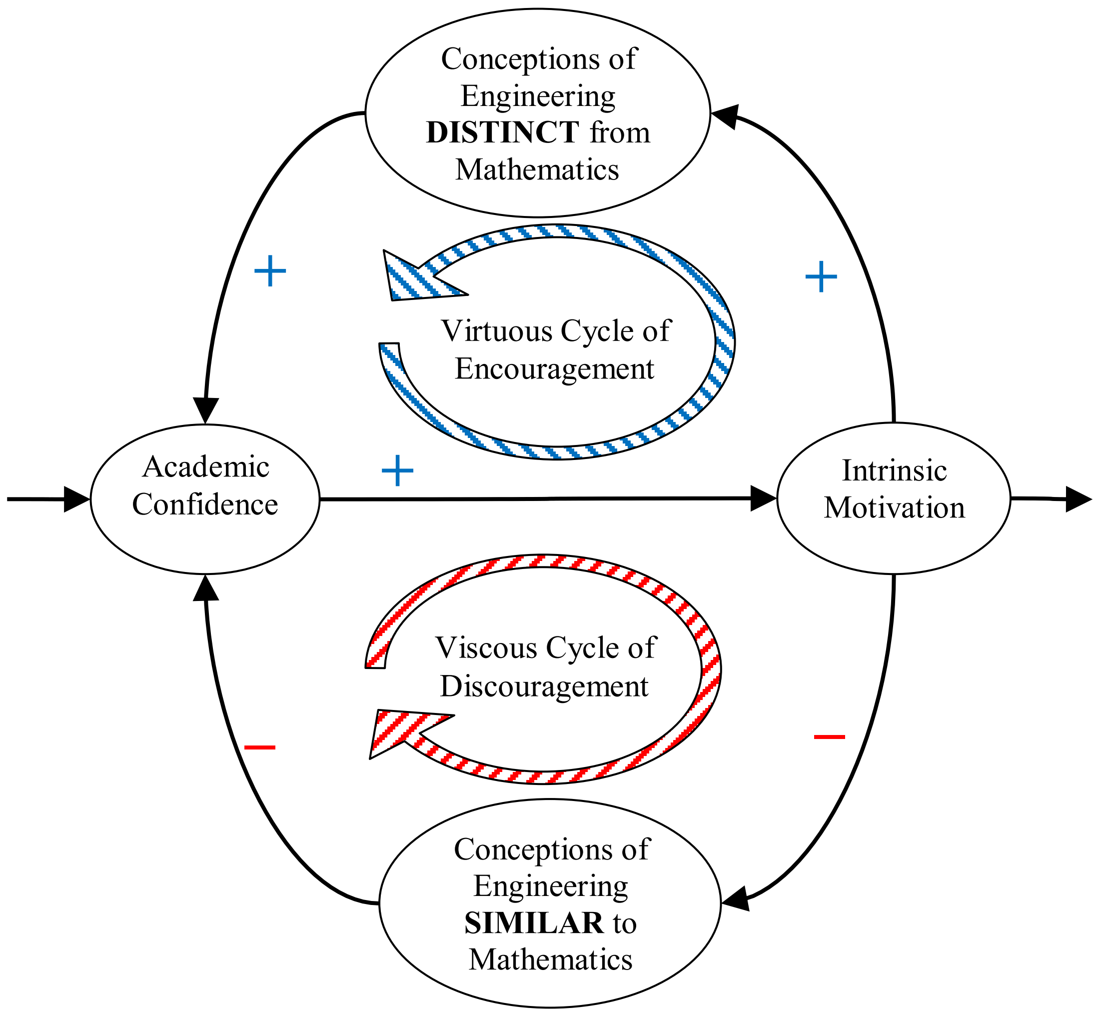


Figure 7.1 - A possible dynamic model that can used to investigate the changes with time in Student Conceptions, Academic Confidence and Intrinsic Motivation

7.5 ***Concluding Remarks***

In conclusion, this PhD study has investigated both the generic experiences of polytechnic engineering students and the specific experiences of a small number of them who had failed mathematics, within an authentic but unique PBL setting. This study has identified issues associated with beliefs about engineering and mathematics, professional persistence, academic confidence, intrinsic motivation and engagement with engineering subjects as key elements, which characterised the experience of learning engineering for the bulk of students in this context. Examining these factors from the perspectives of a few students, who failed mathematics and were hypothesised to be in a disadvantaged position, has illuminated the importance of how conceptions of engineering are formed in engineering studies. This process of forming conceptions of engineering seemed to be connected to academic confidence and intrinsic motivation, which in turn influenced the intention to persist in engineering. How students come to conceptualise engineering, appears to be adversely influenced by their prior experiences with mathematics and conceptions of mathematics.

Only one of the students appeared to have bucked the negative trend caused by a prior failure in mathematics. That student was different because he seemed to have clearly distinct conceptions of mathematics and engineering, and stood apart from his peers in terms of his much greater confidence, motivation and academic performance. It was not certain whether it was his personality or a particular educational encounter he had, that made his experience unique. However, this one student did demonstrate that it is possible to excel in engineering studies even if hindered by prior mathematics failure. His experience validates the suggestion earlier in this chapter that educators could do more to help students to make a clear distinction between the domains of mathematics and engineering. It also raises the question, in a PBL context where learning is largely self-directed, what is the best way for an experienced engineer to share his or her conception of engineering, built up over years of experience, with engineering students?

It is hoped that teachers of engineering consider how this study could stimulate conversation in their campuses as to how they go about educating existing students on the nature of engineering, and how they might investigate some of the other questions that were raised in the 'Future Work' section. For readers in the engineering industry and other areas outside academia, the hope is that this study might be useful as a guide for helping students get the most out of their internship experiences, and for successfully assimilating newly graduated engineering students into the working world. Readers involved in educational policy and enrolment decisions are also invited to use this study as a basis for thinking about educational approaches that enable engineering students to have early contact with "real" engineering, and to consider if current engineering enrolment criteria need to take into account students' conceptions of the field. It is hoped that this study, in some small way, supports future efforts to build more effective, exciting and realistic systems in engineering education.

Post-script: What this Engineer Learnt by doing a Ph.D. in Education

"To every Ph.D. there is an equal and opposite Ph.D., which explains why it is so easy to find expert witnesses who contradict each other."

\- *B. Duggan*

When I started this doctorate back in 2008, I was in my fourth year teaching engineering at a local polytechnic, and I had pipedreams that my doctoral thesis would change the fundamental nature of engineering education. Reflecting on this process three and a half years later, I have to admit that this thesis will not revolutionise the field overnight. In fact, it has probably changed me more than it will ever change the world. Nor am I disappointed; as an educator, I cannot think of a more significant outcome. In this post-script to the dissertation, I will share my reflections on what I have learnt from this doctoral process. I hope this brief self-study inspires others to take up the challenge of doctoral studies as well.

I. <u>Dealing with my own Academic Confidence in Statistics</u>

The notion of investigating the learning experiences of engineering students who were weak in mathematics, was one that I had been toying with for years before starting this doctorate. One reason this was such a compelling idea to me, may have been my own experiences as an engineering student. Though I was not weak in mathematics myself, I never enjoyed the mathematical aspects of my engineering studies. Learning mathematics was hard work, and made harder because I could rarely see the relevance of it. As an engineering student, I prided myself on my ability to avoid learning the mathematics wherever I could, while still managing to solve the problem at hand. This desire to avoid learning mathematics was something that I unsuspectingly carried with me into my professional life.

When I initially framed this doctoral study, I framed it as one that employed primarily qualitative techniques. As a novice exploring qualitative methods, they seemed easier to cope with than having to learn a series of statistical techniques that were new to me. The statistical techniques and tools used in social science research are, in reality, quite different from the mathematics I knew and taught in my discipline of electronics engineering. In honesty, it had been such a long time since I had to learn new mathematical skills, that I was most likely avoiding using any statistical techniques because I was not confident in my ability to master them. By avoiding statistics, I was inadvertently limiting the scope of my own study. However, it was only through exploring the issue of academic confidence in this study, and reflecting on my own decisions, that this became clear to me.

I eventually did have to learn and apply some sophisticated statistical techniques to analyse the quantitative data in this study. The impetus to even consider quantitative methods was my struggle with the qualitative data analysis. After my pilot interviews with students, I could not make sense of complex and wide-ranging themes in the qualitative data. Every theme and code seemed significant and I did not have any basis to focus the coding. It was a colleague, who first suggested that I should run a survey to ascertain the general factors associated with learning, and that this would help me to focus the coding. Even then, I resisted this suggestion until the realisation hit me that my own psychological hang-ups mirrored those of the students. The realisation that my reluctance to use quantitative analysis was due to a psychological hang-up was empowering. It allowed me to re-examine previous decisions and to reframe the study design in an unbiased way, to the betterment of the research outcomes. I still had to do the hard work of learning the statistical techniques, but with this realisation, I stopped standing in my own way.

II. Discovering the Truth about Qualitative Research

> *"Research is hard work, it's always a bit suffering. Therefore, on the other side research should be fun"*
>
> - *Anselm Strauss in conversation (Legewie & Schervier-Legewie, 2004)*

A second significant learning experience was that quantitative analysis was not as hard as I thought, and that qualitative analysis was actually a lot more challenging for me. The reassuring aspects of doing quantitative research were that it was possible to know beforehand what I was looking for in the data, and to plan the data collection, analysis and reporting phases in advance. Once the initial hurdles of learning the appropriate statistical techniques and tools were overcome, it was just a matter of following a clearly laid out path, which had been taken by many researchers before. Qualitative research, by comparison, was like being lost in the wilderness while blindfolded, at least at first.

Personally, I was less concerned, than some other researchers, with the philosophical implications of adopting either a quantitative or a qualitative paradigm. My research paradigm was pragmatic; in the sense that I used whatever methods best suited the research questions and the data that were available. However, in the initial stages of qualitative analysis I struggled with the question of my bias as a researcher. I constantly asked myself if I was over interpreting the data and if the themes that I had identified were generalisable. I was also unprepared for the amount of time it took to code, recode and think about the data. However, perhaps the most disconcerting thing for me was having to go through the cycle of data collection and data analysis multiple times, as every time looked at the data I saw new themes or connections between themes that I did not see before. Both Glaser (1978) and Strauss (1994) speak about how a core category should "emerge" from the data, but I have come to the opinion that the term "emerge" does not give justice to the hard work that I had to put in as a researcher.

I would probably have continued to struggle with qualitative analysis if I had not discovered one simple but essential activity in the research process. This was to start writing even though the data analysis was not complete. Writing and proposing models while I wrote, helped me to organise my thinking and focus my thoughts on essential questions I wanted to answer with the qualitative data. The cycle of data collection, data analysis and writing was what actually made qualitative research a productive and fun experience. In retrospect, I should have started writing much earlier in the doctoral process. I have come to realise that the act of writing is not just about communicating ideas that have been laid out clearly beforehand. Starting the process earlier would have helped me to considerably develop my ideas, even if the product of the writing were to change significantly in the final draft.

The amount of writing I had to do for this dissertation allowed me to reflect on my own writing strategy. Chandler (1992) classified various writing strategies based on an extensive review of the published self-reports of writers. His categories were: (1) Architects who consciously pre-plan, organise, and do little revision; (2) Watercolour Artists who try to write a final draft on the first attempt with little revision; (3) Bricklayers who revise at sentence and paragraph level as they proceed; and, (4) Oil Painters who pre-plan little but rework text repeatedly. Before attempting this dissertation, I would have thought that my writing strategy was that of the Architect, now I think I actually am somewhere between the Bricklayer and the Oil Painter.

III. Learning to Think like an Educational Researcher

> *"We do our science under conditions that physical scientists find intolerable."*
>
> - *Educational Research: The Hardest Science of All (Berliner, 2002, p. 18)*

One of the most important things that I have learnt, but also perhaps one of the most subtle, is to think like an educational researcher. Engineering, like education, is an applied field. Just as engineering draws from physics and mathematics, education draws from sociology and psychology. Engineering research leads to better bridge designs, more efficient electronic circuits and rockets to Mars. Whilst educational research (more modestly), only seems to promote arguments, discourse and discussions about how to improve teaching and learning. Compared to engineering research, the outcomes of educational research seem to be soft, squishy, vague and imprecise. Educational research is a soft science, but to quote Berliner (2002, p. 18) “the important distinction is really not between the hard and the soft sciences … it is between the hard and the easy sciences”. I have learnt that educational research, with its highly contextual nature, ubiquitous interaction between multiple factors and short half-life of findings, is definitely not an easy science to do.

Very early on in the doctoral process, I hypothesised about what the findings from this study would be. I was open to many possible outcomes, but I was confident that prior mathematics performance was somehow related to the cognitive aspects of learning engineering. As I proceeded with the study, I quickly came to realise that the data had a different story to tell and compelled me to investigate the psychological aspects of learning instead. I still suspect that cognitive factors are part of the picture, but the data I had, especially the student interviews, had one clear story to tell and I realised that I would not have been a good educational researcher, if I was not sensitive to that story.

I have learnt that as a researcher in this field, it is paramount that I listen closely to the individuals involved and I am sensitive to both their blind spots and mine. I realised the importance of referring to educational and physiological theories to help make sense of findings, but also the importance of not being overly dependent on theory when initially approaching the data. Because educational research findings are often uncertain and qualified, I have come to appreciate the importance of sound arguments to make a case for the validity of conclusions in this field. This doctoral process reminded me that unlike knowledge in some of the fundamental sciences, knowledge in education is not pursued for knowledge sake alone. Human beings are always at the centre of education, and any research much be justified in terms of potential benefit to them. This may actually be the hardest science of all and I am proud to be contributing to its progress.

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Appendix A – Item-by-item Modification to the Original APPLES Instrument

Original No.	APPLE Survey Original Items	New No.	SEG Student Survey Adapted Items	Remarks
1	What school are you currently attending?	-	Removed	This demographic information is already known
2	What is your current academic standing?	-	Removed	This demographic information is already known
3	When you entered this institution were you:	-	Removed	This demographic information is already known
4	What were you most interested in majoring in when you first came to university? (Choose one)	1	What subject were you most interested in before you first came to polytechnic? (Choose one)	Changed to suite local context. Students don't have a choice of major once they are enrolled in the polytechnic, therefore the question was changed to ask what they were interested in before enrolment.
5	What is your current major or first choice of major? (Mark one)	-	Removed	This demographic information is already known
6	What is your second choice of major or second major/minor? (Mark one or N/A if not applicable)	-	Removed	This demographic information is already known
7	Do you intend to complete a major in	2	Do you intend to complete your	Changed to suite local

	engineering?		engineering diploma?	context.
8	Do you intend to practice, conduct research in, or teach engineering for at least 3 years after graduation?	3	Do you intend to either work in engineering or study engineering for at least 3 years after graduation (or after completing national service for eligible male Singaporeans)?	Changed to suite local context. Term "conduct research" dropped as it's unlikely that diploma graduates would be expected to do research.
9	We are interested in knowing why you are or were studying engineering. Please indicate below the extent to which the following reasons apply to you: Please indicate how strongly you disagree or agree with each of the statements: • Technology plays an important role in solving society's problems • Engineers make more money than most other professionals • My parent(s) would disapprove if I chose a major other than engineering • Engineers have contributed greatly to fixing problems in the world • Engineers are well paid • My parent(s) want me to be an engineer • An engineering	4	We are interested to know why you are studying engineering. Please indicate below how much each of the following reasons apply to you: Please indicate how strongly you disagree or agree with each of the statements: • Technology plays an important role in solving society's problems • Engineering diploma holders make more money than most other diploma holders • My parent(s) would disapprove if I chose a diploma other than engineering • Engineering has contributed greatly to fixing problems in the world • Engineering jobs are well paid • My parent(s) want me to study engineering	Changed to suite local context. Language changed after pilot testing in order to aid understanding. As students were diploma programs and not studying to be professional engineers upon graduation many of the items had to be accordingly modified.

	degree will guarantee me a job when I graduate • A faculty member, academic advisor, teaching assistant or other university affiliated person has encouraged and/or inspired me to study engineering • A non-university affiliated mentor has encouraged and/or inspired me to study engineering • A mentor has introduced me to people and opportunities in engineering • I feel good when I am doing engineering • I like to build stuff • I think engineering is fun • Engineering skills can be used for the good of society • I think engineering is interesting • I like to figure out how things work		• An engineering diploma will guarantee me a job when I graduate • An RP staff has encouraged and/or inspired me to study engineering • A person from outside RP has encouraged and/or inspired me to study engineering • A mentor (from inside or outside RP) has introduced me to people and opportunities in engineering • I feel good when I am doing engineering • I like to build stuff • I think engineering is fun • Engineering skills can be used for the good of society • I think engineering is interesting • I like to figure out how things work	
10	Please indicate how strongly you disagree or agree with each of the statements: • Creative thinking is one of my strengths • I am skilled at solving problems that can have multiple solutions • A mentor has	5	Please indicate how strongly you disagree or agree with each of the statements: • Creative thinking is one of my strengths • I am skilled at solving problems that can have multiple solutions • A mentor (from	Term “mentor” clarified after pilot testing. Students were unclear if this referred to a person from within or outside RP.

	supported my decision to major in engineering		inside or outside RP) has supported my decision to major in engineering	
11	Rate yourself on each of the following traits as compared to your classmates. We want the most accurate estimate of how you see yourself.	6	Rate yourself on each of the following traits as compared to your classmates. Please provide the most accurate estimate of how you see yourself.	Language depersonalised in order to be consistent with other surveys that are run within the institution. "We want" changed to "please provide".
12	How important do you think each of the following skills and abilities is to becoming a successful engineer?	7	How important do you think each of the following skills and abilities is to being successful in engineering?	Graduates from the institution will not be professional engineers but will be doing engineering work. Therefore the term "successful engineer" was changed to "successful in engineering".
13	Please rate your satisfaction with this institution on each aspect of campus life listed below. (Mark N/A if you do not have experience with this aspect.) • Quality of instruction • Availability of instructors • Quality of advising by instructors • Academic advising	8	Please rate your satisfaction with RP on each aspect of campus life listed below. (Mark N/A if you do not have experience with this aspect.) • Quality of teaching • Availability of facilitators • Quality of advising by facilitators • Advising on career or	Changed to suit local context. Instructors are called facilitators in RP. And the term "teaching" was changed to "instruction" after pilot testing.

			further studies • Overall quality of your polytechnic experience	
14	During the current school year, what portion of your classes have used the following teaching methods?	-	Removed	All students in RP go through the same teaching method. They work exclusively on team projects.
15	Please rate the overall quality of your collegiate experience so far:	8	• Overall quality of your polytechnic experience	"Collegiate" changed to "polytechnic", to suit local context. Integrated with the previous question, question 8, as it shares the same Likert scale.
16	Think about the engineering, math or science classes you are taking/have taken during the current school year. Indicate how often you: (Mark N/A if you have not taken any engineering related classes.) • Came late to engineering class • Skipped engineering class • Turned in engineering assignments that did not reflect your best work • Turned in engineering assignments late	9	Think about the engineering, mathematics or science classes you are taking/have taken during the current school year. Indicate how often you: • Came late to class • Skipped class • Submitted assignments that did not reflect your best work • Submitted assignments late	N/A option removed as all students would have taken at least one engineering, mathematics or science class Word "engineering" dropped from items so as not to confuse students responding based on science or math classes.

17	Think about the liberal arts classes (not engineering, math, or science classes) you are taking/have taken during the current school year. Indicate how often you: (Mark N/A if you have not taken any liberal arts classes.) • Came late to liberal arts class • Skipped liberal arts class • Turned in liberal arts assignments that did not reflect your best work • Turned in liberal arts assignments late	10	Think about the general or elective classes (not engineering, mathematics, or science classes) you are taking/have taken during the current school year. Indicate how often you: (Mark N/A if you have not taken any general or elective classes.) • Came late to class • Skipped class • Submitted assignments that did not reflect your best work • Submitted assignments late	Changed to suit local context. “Liberal arts” changed to “general or elective classes”. Word “liberal arts” dropped from items in order to make them more succinct.
18	How well are you meeting the workload demands of your coursework?	11	How well are you meeting the workload demands of your course?	Changed to suit local context. Changed after pilot testing, for the sake of clarity. “Coursework” changed to “course”.
19	How stressed do you feel in your coursework right now?	12	How stressed do you feel in your course right now?	As above
20	During the current school year, how much pressure have you felt with each of the following? Likert scale items: o No Pressure o Moderately Low Pressure o Moderate Pressure o Moderately High Pressure o High Pressure	13	During the current school year, how much pressure have you felt with each of the following? Likert scale items: o No Pressure o Low Pressure o Moderate Pressure o High Pressure o Extreme Pressure	Likert scale items modified to be more succinct. “I prefer not to answer” option dropped from Likert scale.

	o I prefer not to answer			
21	During the current school year, how often have you interacted with your instructors (faculty, teaching assistants) in your engineering, math, or science classes (e.g. by phone, e-mail, IM, or in person)? (Mark N/A if you have not taken any engineering, math, or science classes this year.) • Instructors during class • Instructors during office hours • Instructors outside of class or office hours	14	During the current school year, how often have you interacted with your facilitators in your engineering, mathematics, or science classes (e.g. by phone, e-mail, IM, or in person)? • Facilitators during class • Facilitators during office hours • Facilitators outside of class or office hours	N/A option removed as all students would have taken at least one engineering, mathematics or science class. “Instructors” changed to “Facilitators” to suit local context.
22	Some people are involved in non-engineering activities on or off campus, such as hobbies, civic or church organizations, campus publications, student government, social fraternity or sorority, sports, etc. How important is it for you to be involved in these kind of activities?	15	Some people are involved in non-engineering activities on or off campus (such as interest groups, hobbies, civic or religious organisations, campus publications, student union, sports, etc.). How important is it for you to be involved in these kinds of activities?	Changed to suit local context “I prefer not to answer” option dropped from Likert scale.
23	How often are you involved in the kinds of non-engineering activities described above?	16	How often are you involved in the kinds of non-engineering activities described in the previous question (in question 15)?	“Above” changed to “previous question (in question 15)” for the sake of clarity. I prefer not to answer” option dropped from Likert scale.

24	What is your level of involvement in student engineering activities such as engineering clubs or societies?	17	What is your level of involvement in student engineering activities such as engineering clubs or engineering related interest groups?	Changed to suit local context “I prefer not to answer” option dropped from Likert scale.
25	Since coming to college, have you had any research experience(s)? (Mark one)	18	Since coming to polytechnic, have you had any research experience(s)? (Mark one)	“College” changed to “polytechnic”, to suit local context. “I prefer not to answer” option dropped from Likert scale.
26	Before college, how much knowledge did you have about the engineering profession?	19	Before polytechnic, how much knowledge did you have about the engineering profession?	“College” changed to “polytechnic”, to suit local context. “I prefer not to answer” option dropped from Likert scale.
27	Since entering college, how much knowledge have you gained about the engineering profession?	20	Since entering polytechnic, how much knowledge have you gained about the engineering profession?	“College” changed to “polytechnic”, to suit local context. “I prefer not to answer” option dropped from Likert scale.
28	How much exposure have you had to a professional engineering environment as a visitor, intern, or employee?	21	No change to question	“I prefer not to answer” option dropped from Likert scale.
29	How did you gain your knowledge about the engineering profession? (Mark all that apply)	22	How did you gain your knowledge about the engineering profession? (Mark all that apply)	Options clarified and changed to suit local context

	☐ From being a visitor ☐ From being a <u>co-op student or intern</u> ☐ From being an employee ☐ From a family member ☐ From a close friend ☐ From school-related experiences (i.e., a <u>professor</u> or class) ☐ Other: ☐ <u>I prefer not to answer</u>		☐ From being a visitor ☐ From being a an <u>intern (i.e., work attachments)</u> ☐ From being an employee ☐ From a family member ☐ From a close friend ☐ From school-related experiences (i.e., a <u>facilitator</u> or class)	"I prefer not to answer" option dropped from Likert scale.
30	Do any of your immediate family members (parents, siblings) hold an engineering degree?	23	Do any of your immediate family members (parents, siblings) hold an engineering <u>diploma or</u> degree?	Changed to suit local context. "I prefer not to answer" option dropped from Likert scale.
31	Do you see yourself continuing in an engineering major?	-	Removed	Not relevant for local context
32	Do you see yourself pursuing a career in engineering?	-	Removed	In pilot testing was found that at this stage of their education most students did not have a strong opinion their future careers and could not make a distinction between career in engineering and working in engineering.

33	How likely is it that you would do each of the following after graduation? • Work in an engineering job • Work in a non-engineering job • Go to graduate school in an engineering discipline • Go to graduate school outside of engineering	24	How likely is it that you would do each of the following after graduation? • Work in an engineering job • Work in a non-engineering job • Go to university to study an engineering discipline • Go to university to study a non-engineering discipline	Changed to suit local context. "Graduate school" changed to "university".
34 to 49	Removed	-	Removed	Questions removed because we are not looking at these factors or because the demographic information is already available to us.
50	Is there anything you want to tell us about your experiences in engineering that we haven't already asked you about?	25	No change to question	No change

Appendix B – Student Survey Variables

16 multi-item variables That measure concepts relating to factors that influence students' intentions to major in engineering and eventually, to continue studying or work in an engineering field.

1. **Motivation (Financial)**
   4b. Reason: Engineers make more money than most other professionals do
   4e. Reason: Engineers are well paid
   4g. Reason: An engineering degree will guarantee me a job when I graduate

2. **Motivation (Parental Influence)**
   4c. Reason: My parents would disapprove if I chose a major other than engineering
   4f. Reason: My parents want me to be an engineer

3. **Motivation (Social Good)**
   4a. Reason: Technology plays an important role in solving society's problems
   4d. Reason: Engineers have contributed greatly to fixing problems in the world
   4n. Reason: Engineering skills can be used for the good of society

4. **Motivation (Mentor Influence)**
   4h. Reason: A faculty member, academic advisor, teaching assistant or other university affiliated person has encouraged and/or inspired me to study engineering
   4i. Reason: A non-university affiliated mentor has encouraged and/or inspired me to study engineering
   4j. Reason: A mentor has introduced me to people and opportunities in engineering

5c. Agree/disagree: A mentor has supported my decision to major in engineering.

5. **Motivation (Intrinsic, Psychological)**

4k. I feel good when I am doing engineering

4m. I think engineering is fun

4o. I think engineering is interesting

6. **Motivation (Intrinsic, Behavioural)**

4l. I like to build stuff

4p. I like to figure out how things work

7. **Confidence in Mathematics and Science Skills**

6d. Confidence: Mathematics ability

6e. Confidence: Science ability

6g. Confidence: Ability to apply Mathematics and science principles in solving real world problems

8. **Confidence in Professional and Interpersonal Skills**

6a. Confidence: Self-confidence (social)

6b. Confidence: Leadership ability

6c. Confidence: Public speaking ability

6f. Confidence: Communication skills

6h. Confidence: Business ability

6i. Confidence: Ability to perform in teams

9. **Confidence in Solving Open-ended Problems**

5a. Agree/disagree: Creative thinking is one of my strengths (4 pt. scale)

5b. Agree/disagree: I am skilled at solving problems w/multiple solutions (4 pt. scale)

6j. Confidence: Critical thinking skills (5 pt. scale)

10. <u>Perceived Importance of Mathematics and Science Skills</u>

7d. Perceived importance: Mathematics ability

7e. Perceived importance: Science ability

7g. Perceived importance: Ability to apply Mathematics and science principles in solving real world problems

11. <u>Perceived Importance of Professional and Interpersonal Skills</u>

7a. Perceived importance: Self Confidence (social)

7b. Perceived importance: Leadership ability

7c. Perceived importance: Public speaking ability

7f. Perceived importance: Communication skills

7h. Perceived importance: Business ability

7i. Perceived importance: Ability to perform in teams

12. <u>Curriculum Overload</u>

11. How well are you meeting the workload demands of your coursework?

12. How stressed do you feel in your coursework right now?

13a. During the current year, how much pressure have you felt with course load?

13b. During the current year, how much pressure have you felt with course pace?

13c. During the current year, how much pressure have you felt with balance between social and academic life?

13. <u>Academic Disengagement—Liberal Arts Courses</u>

10a. Frequency: Came late to liberal arts class

10b. Frequency: Skipped liberal arts class

10c. Frequency: Turned in liberal arts assignments that did not reflect your best work

10d. Frequency: Turned in liberal arts assignments late

14. <u>Academic Disengagement—Engineering-related Courses</u>

9a. Frequency: Came late to engineering class

9b. Frequency: Skipped engineering class

9c. Frequency: Turned in engineering assignments that did not reflect your best work

9d. Frequency: Turned in engineering assignments late

15. <u>Frequency of Interaction with Instructors</u>

14a Frequency of interaction: Instructors during class

14b. Frequency of interaction: Instructors during office hours

14c. Frequency of interaction: Instructors outside of class or office hours

16. <u>Satisfaction with Instructors</u>

8a. Satisfaction: Quality of instruction

8b. Satisfaction: Availability of instructors

8c. Satisfaction: Quality of advising by instructors

8d. Satisfaction: Academic Advising

Additional variables that are either single item variables or descriptors of the student experience.

17. <u>Academic Persistence</u>

2. Do you intend to complete a major in engineering?

18. <u>Professional Persistence</u>

3. Do you intend to practice, conduct research in, or teach engineering for at least 3 years after graduation?

Related Items:

24a. How likely is it that you would do each of the following after graduation: Work in an engineering job

24b. How likely is it that you would do each of the following after graduation: Work in a non-engineering job

24c. How likely is it that you would do each of the following after graduation: Go to graduate school in an engineering discipline

24d. How likely is it that you would do each of the following after graduation: Go to graduate school in a non-engineering discipline

19. <u>Exposure to the Engineering Profession</u>

21. How much exposure have you had to a professional engineering environment as a visitor, intern, or employee?

20. <u>Knowledge of the Engineering Profession</u>

19. Before college, how much knowledge did you have about the engineering profession?

20. Since entering college, how much knowledge have you gained about the engineering profession?

22. Related items: How did you gain your knowledge about the engineering profession?

23. Do any of your immediate family members (parents, siblings) hold an engineering degree?

21. <u>Extracurricular Involvement (Engineering and Non-Engineering)</u>

15. Importance of non-engineering activities on or off campus

16. Involvement in non-engineering activities

17. Level of involvement: Student engineering activities such as engineering clubs or societies

22. <u>Research Experience</u>

18. Since coming to college, have you had any research experiences in engineering and/or non-engineering areas?

23. <u>Overall Satisfaction with Collegiate Experience</u>

8d. Rate the overall quality of your collegiate experience so far

Appendix C – Aide-Memoire of Questions for Interviews

1. Why did you decide to take part in this interview?
2. What about engineering have you learnt so far?
3. What strategy do you use to learn engineering?
4. How important are your classmates in your learning of engineering?
5. How do you know when you've learnt something about engineering well?
6. Recall a specific engineering problem that you've encountered. Can you describe how you dealt with this problem?
7. How would you answer the question "What is engineering?"
8. Has your perspective of engineering changed since coming to the polytechnic?
9. Do you intend to continue studying or working in an engineering related field when you graduate?
10. How important is maths in engineering? How is engineering different from mathematics?
11. Other students have said that in addition to maths, engineering is 'hands-on'. What do think of this?
12. Is science a part of engineering? How so?
13. How would you answer the question "What is mathematics?"
14. What maths do you think you've understood really well? What maths has been the most challenging to you?
15. How do you usually go about learning some maths?
16. Has the maths you've learnt been useful to you? How has it helped you learn engineering?
17. How has PBL affected how you learn?
18. If you could change anything about the approach to teaching engineering here, what would it be?
19. What other questions should I have asked you in this interview?

Appendix D – Proof of Ethics Approval

REPUBLIC

Woodlands Campus
9 Woodlands Avenue 9
Singapore 738964
Tel: (65) 65103000 Fax: (65) 6415-1310
Website: www.rp.sg

Standing Committee on Ethics in Research Involving Humans (SCERH)
First Floor, Building 3E
Room 111, Research Office
Monash University
Victoria
AUSTRALIA, 3800

RE: Letter of approval to conduct research

Dear Ethics Committee,

This letter confirms that Preman Rajalingam has approval to conduct the following research project at Republic Polytechnic.

> "Adapting to Problem Based Learning: How the Mathematically Challenged Complete an Engineering Diploma"

It is understood that his is conducting this research project with Jeffrey John Loughran a Professor in the Department of Education towards a PhD at Monash University. I am assured that he will conduct his research in line with the ethical research guidelines at Republic Polytechnic.

Yours Sincerely

[redacted]

Glen O'Grady
Director
Centre for Educational Development

CENTRE FOR EDUCATIONAL DEVELOPMENT

PEOPLE DEVELOPER SINGAPORE · SINGAPORE QUALITY CLASS · SINGAPORE HEALTH AWARD · SINGAPORE INNOVATION CLASS

MONASH University

Standing Committee on Ethics in Research Involving Humans (SCERH)
Research Office

Human Ethics Certificate of Approval

Date:	**16-May-2008**
Project Number:	**CF08/0958 - 2008000477**
Project Title:	**Adapting to Problem Based Learning: How the Mathematically Challenged Complete an Engineering Diploma**
Chief Investigator:	**Prof Jeffrey Loughran**
Approved:	**From: 16-May-2008 To: 16-May-2013**

Terms of approval

1. The Chief investigator is responsible for ensuring that permission letters are obtained and a copy forwarded to SCERH before any data collection can occur at the specified organisation. **Failure to provide permission letters to SCERH before data collection commences is in breach of the National Statement on Ethical Conduct in Human Research and the Australian Code for the Responsible Conduct of Research.**
2. Approval is only valid whilst you hold a position at Monash University.
3. It is the responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval and to ensure the project is conducted as approved by SCERH.
4. You should notify SCERH immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
5. The Explanatory Statement must be on Monash University letterhead and the Monash University complaints clause must contain your project number.
6. **Amendments to the approved project including changes in investigators:** Require the submission of a Request for Amendment form to SCERH and must not begin without written approval from SCERH. Substantial variations may require a new application.
7. **Future correspondence:** Please quote the project number and project title above in any further correspondence.
8. **Annual reports:** Continued approval of this project is dependent on the submission of an Annual Report. This is determined by the date of your letter of approval.
9. **Final report:** A Final Report should be provided at the conclusion of the project. SCERH should be notified if the project is discontinued before the expected date of completion.
10. **Monitoring:** Projects may be subject to an audit or any other form of monitoring by SCERH at any time.
11. **Retention and storage of data:** The Chief Investigator is responsible for the storage and retention of original data pertaining to a project for a minimum period of five years.

[redacted]

Professor Ben Canny
Chair, SCERH

Cc: Mr Preman Rajalingam

Postal – Monash University, Vic 3800, Australia
Building 3E, Room 111, Clayton Campus, Wellington Road, Clayton
Telephone +61 3 9905 5490 Facsimile +61 3 9905 1420
Email scerh@adm.monash.edu.au www.monash.edu/research/ethics/human/index/html
ABN 12 377 614 012 CRICOS Provider #00008C

Appendix E – Explanatory Statement and Consent Form

Explanatory Statement

23 Mar. 08

Explanatory statement for Republic Polytechnic students enrolled in engineering programmes.

Title: Adapting to Problem-Based Learning: How the Mathematically Challenged Complete an Engineering Diploma

This information sheet is for you to keep.

Dear _________________

My name is Preman Rajalingam and I am conducting a research project with Jeffrey John Loughran a Professor in the Department of Education towards a PhD at Monash University. This means that I will be writing a thesis, which is the equivalent of a 200-300 page book. I'm also a facilitator at Republic Polytechnic (RP) with the Centre for Educational Development.

Previously you received a letter from RP inviting you to attend this meeting and discuss this project. The aim of this project to understand how students, who may find mathematics challenging, are able to learn engineering in a dedicated PBL setting like RP. I have approached you to take part in this study because I'm interested in understanding your perspectives on how you cope with studying engineering at RP.

I hope to describe the educational experience and understand the coping processes of polytechnic students who are enrolled in problem-based engineering programmes. If I can understand how different students deal with their diploma programmes then I can provide recommendations for future practice to improve the instruction and preparation of students who have difficulties coping.

This study will require your participation in a series of semi-structured interviews with the researcher over the course of a year. The interviews will be audio recorded (with participants' permission) and transcribed by the researcher to be analysed. A transcript of data collected from you will be given to you for approval before it is included in the write up of the research. All of the interviews will be conducted at the Republic Polytechnic at a time convenient for you and your involvement will not exceed two hours a month. Any information that you may provide will be treated as strictly confidential and will not be made available to anyone else other than the researcher.

Being in this study is voluntary and you are under no obligation to consent to participation. In fact, if you are not comfortable continuing you may withdraw and the information collected from you will be discarded.

In the interest of maintaining confidentiality, a pseudonym will be used instead of your real name. Furthermore, any reports that result from this study will not allow for any individual to be identified. Audio recordings, notes and other documents arising from this study will be kept under lock-and-key in a secure location for a period of five years, accessible only to the researcher.

If you would like to be informed of the progress of the study or the research finding, please contact **Preman Rajalingam** on [redacted] or at [redacted]

If you would like to contact the researchers about any aspect of this study, please contact the Chief Investigator:	If you have a **complaint** concerning the manner in which this research **(Project Number:CF08/0958 – 2008000477)** is being conducted, please contact:
Professor John Loughran Department of Education Building 6 Room 335 Monash University VIC 3800 Tel: +[redacted] Fax:+[redacted] Email: [redacted]	Human Ethics Officer Standing Committee on Ethics in Research Involving Humans (SCERH) Building 3e Room 111 Research Office Monash University VIC 3800 Tel: +61 3 9905 2052 Fax: +61 3 9905 1420 Email: scerh@adm.monash.edu.au

Thank you.

Preman Rajalingam

Consent Form - ***For students enrolled in engineering programmes.***

Title: *Adapting to Problem-Based Learning: How the Mathematically Challenged Complete an Engineering Diploma*

NOTE: This consent form will remain with the researcher for their records

I agree to take part in the Monash University research project specified above. I have had the project explained to me, and I have read the Explanatory Statement, which I keep for my records. I understand that agreeing to take part means that I am willing to:

I agree to be interviewed by the researcher
☐ Yes ☐ No
I agree to allow the interview to be audiotaped or videotaped
☐ Yes ☐ No
I agree to make myself available for a further interview if required
☐ Yes ☐ No

I understand that I will be given a transcript of data concerning me for my approval before it is included in the write up of the research.

I understand that my participation is voluntary, that I can choose not to participate in part or all of the project, and that I can withdraw at any stage of the project without being penalised or disadvantaged in any way.

I understand that any data that the researcher extracts from the interview for use in reports or published findings will not, under any circumstances, contain names or identifying characteristics.

I understand that data from the interviews will be kept in a secure storage and accessible to the research team. I also understand that the data will be destroyed after a 5-year period unless I consent to it being used in future research.

____
Participant's name

____
Signature

____
Date

Appendix F – Sample Interview Transcript

Transcribed Interview between Researcher and a Diploma in Biomedical Electronics Second-Year Student, Vick (Pseudonym)

Date of Interview: 9th October 2008 (first interview)
Interviewer: Preman (PRE)
Interviewee: Vick (Pseudonym) (VIC)
Duration: 00:25:00

PRE:

Ok. Thanks Vick. So we start with first question. In your own opinion, right…You're in the second year now, second semester? So what engineering have you learnt so far?

VIC:

Ok basically, it's more of the skills in engineering for example, right now, PCB, I'm learning PCB. It's actually hands on. So that I feel of all the engineering I've been learning so far … I think that is the most that I tend to do better, every lesson. Really perform better, every lesson because its hands on you see. And it's something that's proven scientifically. That when you do something with hands you tend to not forget it, even if you want to forget it. But for other engineering modules that I have taken, I practically have to go home to practice, revise, to make sure I … to keep in touch… and other modules I cannot fail to skip or be absent … you know?

PRE:

If you were to mention one thing about Engineering which you feel that while one year ago you really didn't know and now you know it, what would it be?

VIC:

In depth of Math. From what I learnt from Secondary school I thought that was that was what was gonna be. People say that you need that Math to do well in Engineering, but when I came into Engineering I kinda find that actually what I learnt in Secondary School is totally not relevant to what I'm learning now. Maybe one, two formulas ya, but the whole gist of it is nothing to do with what I am learning in Engineering. It's totally ... Engineering is like a totally different Math.

00:01:49

PRE:

Ok. We'll come back to that in a little bit, but usually how do you go about learning Engineering. What's your strategy?

VIC:

Basically what I do is … I know that my Math is not at that level so what I do is … my brother actually did Engineering also, a diploma, but he did it in Singapore Poly. His Course in RP is known as DCAE so he actually has some notes, so although most of the modules are not the same … modules like Linear and Digital Electronics he has the notes … so what I do is I look through his notes, I try to understand so when I come for the lesson hopefully that er, I am able to just squeeze through. I know what's going on instead of being like stone you know? ... Really donno what's going on.

PRE:

When you look through his notes, what do you look for? You look for the examples? The equations? What's most helpful to you?

VIC:

When I'm looking through his notes, first I look through what the book actually says and when I don't understand what the book actually says … cos my brother tends to write notes, short point form notes around, so when I see I don't understand what that passage is talking in the text book I tend to look at the notes … the point form notes he has written.

00:03:04

PRE:

Ok. You said you learnt PCB well and you're confident. How do you know that you've learnt Engineering well?

VIC:

How do I know?

PRE:

When you've learnt a bit of Engineering well. What makes you realise that you've done it well?

VIC:

Probably the fact that when you do something, when you come back the next week to do it, you perform better. You know that you're performing better than last week. For example, Linear or whatever module. Say first lesson you struggle, but when you come back to second lesson, not only are you able to recap what you do in the first lesson, but also show significant improvement in the second lesson. Probably that shows that, you know, you are on the right track … learning.

00:03:56

PRE:

Just be a bit specific. Can you recall a specific engineering problem you've encountered in Linear or in PCB? Tell us how you approached solving that problem.

VIC:

Ok. This happened in Sem 1 [Semester 1].

PRE:

Right.

VIC:

Year 2 sem 1. Its known as circuit analysis.

PRE:

I used to teach that module

VIC:

Circuit analysis ... Um what happened was because I did second analysis on the first few problems I totally didn't understand, because it was not what I learnt in Secondary School and the Math was too complex for me. So I had to actually sit down and try to revise while my friends were doing actually better than me. So I had to constantly ask them for help and stuff. But then as lessons went on I kinda got hold of it. Although I did not perform up to their standard I know that there is an improvement in me because I was struggling in the first few lessons. But after that I was able to actually do the thing. Do the problems without even asking them. Only for small, small issues then I had to… go and ask them.

00:05:03

PRE:

Do you recall the problems?

VIC:

The problem was more on a super-equation. First I was struggled with a super-equation then when it went on I was able to do with the help of super-equation. I used that same understanding to do note analysis and loop analysis.

PRE:

So you applied one understanding to the other understanding. And it worked well for you?

VIC:

Eventually I got A's for both lessons.

PRE:

Very good…very good. So considering all your experience with Engineering and what you've heard [about] Engineering if someone were you ask you that question…What is Engineering? How would answer that question?

VIC:

Math, Math and all Math

PRE:

Math, Math and all Math?

VIC:

Ya. But seriously, if they were to ask me I would tell them that they would need Maths from what they learnt from Secondary school, but not entirely. There are certain things that when you come over to Polytechnic and you look at the Math you will realise that it has nothing to do with Secondary school. But, certain Math...more of Math as in calculation but more of the Science like Ohm's Law, Kirkoff's voltage following laws and stuff. There's this kind of laws that you learn in Secondary school that when you come to Poly to study Engineering right..this [has] to be at the back of your head. You cannot come to Poly and start studying those laws, according to me, because I only remembered Holmes law but I couldn't remember Kirkoff's voltage law. Voltage and current. And I had to come over to…when I came over to Poly I had to recap that. That really took a lot of time. Ya, kinda pulled me back.

00:06:47

PRE:

Ok. How important is Math in Engineering? Let's say that someone was asking you?

VIC:

How important is Math? If you look at… ok… compared to secondary school Math… In Polytechnic, Math is important, but it's more of the Science that is involved in Engineering that is important, because I feel that Maths…what I have experienced so far …I feel that the Maths that we do, is just the calculation of what we do in Science. You get what I mean? It's more of you gotto know the theory and everything in Science first and Math will just follow. Follow behind. It becomes easy when you can understand the thing. It's more of the understanding.

PRE:

Ok. So let's ask a question. How are Engineering, Math and Science different?

VIC:

Probably in Secondary school Math was very calculation based. Different calculations coming in. Science was more of very theory based. I mean, there were practicals, but very theory based. Going into fundamentals of Science. And even in Science they had three divisions where its Physics, Chemistry, Bio, you know? Things like that? But for Math its more of the Physics portion that gets more involved. Like Ohm's Law? Everything is actually all under Physics. Not under Chem or Bio.

PRE:

Engineering is closer to Science instead of Math

VIC:

Ya, probably 70% towards Science and 30% towards Math.

00:08:29

PRE:

Is there anything about Engineering which is completely different from Science and Math? Or you think its actually just a mixture of Science and Math?

VIC:

It is a mixture of Science and Math, but some portions of Engineering, its nothing to do with Science and Math. Like PCB.

PRE:

Mmm..uh

VIC:

It's just er..hands on you know? It's nothing to do with Science and Math. Digital Electronics. It has nothing to do with Science and Math. Math probably calculation but Digital Electronics is more of er circuit based you know? So it's probably er these two modules.

PRE:

OK..Mmm…uh…ok since we're talking about Math, just now I asked you a question. What do you think Engineering is? If someone were to ask you a question?. What do you think Math is? What would you say?

VIC:

Nothing but er...intensive calculation.

PRE:

Nothing but that…ok..ok. Um….How do you get better at Math?

VIC:

Practice. Practice, practice, practice!

00:09:35

PRE:

Mmm..uh. Ok I'm just curious. It's not in my questions, but what do you think Science is?

VIC:

Err…Science …probably if you ask me…Science is more of understanding everything around us. Everything wrong. From why we see white colours. Why we see colours and everything. Basically Science is everything.

PRE:

Ok, so Science helps you understand everything you a bit better. And Math doesn't help you understand?

VIC:

Um … understand. I feel Math is more of calculation. Understand… ya maybe in circuitwise you get to understand how this electronic device or this component works. Ya maybe the fundamentals. With Math you understand how the component works. More of that kind of issues, but not around us, ya.

00:10:38

PRE:

Ok Back to Math. What Math have you learnt so far in your Engineering Course which you didn't learn in Secondary school.

VIC:

About amplifiers. Basically about amplifiers. Since Sem 1…Year 2, Sem 1 till now I have been learning all about amplifiers. About how they amplify, the different type of amplifiers, operational difference, inverted, non-inverted, you know? This kind of amplifiers we didn't learn in Secondary school and everything. But how we go upon solving this is a combination of Science, Science laws and Math calculations. The basic divisions, the fine, ya.

PRE:

So in the last you know…your Engineering education so far, what Math do you think you understood really well? And why do you think…what has helped you understand that Math really well?

VIC:

What has helped me? Usually for my case, I tend to get the full picture, although we do presentations and stuff. I feel that I have never… I am not able to understand the whole picture, the gist of the problem until the Faci [Facilitator] actually presents the 6th presentation - the 6th P. Because I feel that the 6th P… the Fasci actually includes things that we have talked about… discussed about. Things that we have not discussed about. And things that are relevant that we didn't touch on. So 6th P is actually the summary, so I feel that after the 6th P then I can actually tell how much I understand, how much I don't understand.

00:12:36

PRE:

Ok. I mean, you've touch on many different types of Math. You touched on Laplace, you touched on amplifier formulae and all that. If you have to pick one thing which you're most confidant in, which one would you pick?

VIC:

Can you please repeat that question?

PRE:

Like all the different kinds of Math that you use. Which aspect of Math are you most confident in now?

VIC:

[pause] The applying of the formulas. You go through the website, and you look for the formulas. You don't try to understand the formulas, just see the type of formulas they use. Then you apply those formulas and that aspect ya. But how it comes about previous to that formula, then I'm not sure. Like using of the formulas is my biggest strength.

00:13:21

PRE:

Um..uh. How should you go about learning some Math if you don't know the Math? Let's say you have to learn some Math to solve a certain problem.

VIC:

I'll try my best. I'll …usually we have worksheets right?

PRE:

Mm…uh

VIC:

So what happens is uh… we look through the worksheets. We try to understand. I especially will try to understand through the worksheets. If it still doesn't work, because worksheets is actually a step by step. So even afer with the aid of the worksheet I am not able to understand, I will ask my friends. Cos usually in a class there are students who are … who would know how to do. But in a worse case scenario even if they donno how to do, usually what I do is er first meeting, students do the FMT, I tend to look through the worksheet. I try. I am not so participative in FMT. I try to get to the problem. So that by the time I got any questions I can ask in the first meeting or I can push it to the second meeting and clear my questions. So, that by the third meeting I know what I want to present. That's how I do my …

00:14:27

PRE:

Ok, ok. Um. Has the Math that you have learnt so far been useful to you? Either in here or in Secondary school? And how has it helped you?

VIC:

Basically Secondary school Math … some of the Math that I have learnt actually acts as a fundamental basic. Like basic addition, subtraction, division. Using of formulae that you learnt in Secondary School. Certain formulae. They come back … they come in handy.

PRE:

How about the Math you've learnt in RP?

VIC:

[pause] Probably if you would ask me I would say that Math that we learnt in Polytechnic … not only that we learn in RP, in any Poly. Engineering Math is totally different. It's a different aspect. You will find that probably what I can say is that Secondary school Math is more general, whereas in Poly, the Math is very specific. Like Engineering Maths, this is how it goes. Probably Accounts, this is how it goes. So there is this division.

00:15:36

PRE:

Is it easier? Engineering Math than Secondary school Math?

VIC:

I find Engineering Math easier than Secondary school Math, because straight to the point. I know what I am doing. I know what I'm supposed to do to find… Whereas for Secondary school Math sometimes that's not the case. They like to play around the words. Ya, even in Engineering Math when they play around the words, at the end of the day you still know what they want. It's like…there's this route, there's this path that Engineering follows so as long as you follow the path you know why you are going there.

00:16:16

PRE:

What do you mean play around with words? Can you give me an example?

VIC:

Like say they want you to find something, but they manipulate the words to make it look like you're supposed to find something else. And you're supposed to…. In the end they play around, like make it sound as if you're supposed to use this to find something, but actually this is the… Like A&B they give you a method, they want you to find A, but they make it look like, they make the sentence structure as if they want you to use A to find B. B is actually not even involved.

00:17:01

PRE:

Ok, so Engineering Math is more straight forward.

VIC:

Ya more straight forward.

PRE:

If they want you to find A they tell you…

VIC:

If they want you to find A they will say find A, but use the aid of B. Something like that.

00:17:10

PRE:

Ok. If you were not in a PBL environment studying Engineering … OK lets ask, being in a PBL environment studying Engineering, how does it affect your approach to Engineering?

VIC:

Its more tedious. It's more tedious, ya. Because I feel there are certain subjects that you can go on with PBL, but certain subjects it just comes from the content. From hardcore book based. Die die you have to study from book. Such subjects would be Math and Science. You cannot, I feel that, it's not say cannot. It's um … When you use PBL for such subjects like Math and Science you kind of loose out in content. So the amount of knowledge you're supposed to gain compared to other Polytechnic students, we are lesser … the gain that we have. That's what I feel. Maths and Science.

00:18:12

PRE:

If you were not in a PBL environment, what would you do differently?

VIC:

Um. Probably it's the same thing from what we do in lectures, textbook, homework. Just following but that would have given more practice and that would have made it more stable for Math and Science students.

00:18:35

PRE:

And you find that would be better or?

VIC:

For Math and Science ya. I definitely feel you have to go book based. By book. Although people say… I am not saying PBL is not good. I feel PBL is good in… It has its pros and cons. But when it comes to Math and Science we can say that its efficiency is very, very minimum.

00:18:55

PRE:

So in what way is it beneficial for Engineering? PBL?

VIC:

More of independent learning?... Because most of the modules, the Facilitators do not give us the data sheet so we have to actually know the…we have to actually go find the data sheet. And best of all they don't teach us how to refer to the data sheet. We have to learn to refer to the data sheet. So in the beginning a lot of students learnt by actually burning their circuits you know? Things like that. They learn from experience. So such experiences right…when put in real life right. These experiences. You may forget the things that you learn like theoretically based but when it comes to these experiences right… when you apply it, the chances that you will make mistake is lesser, because you already went through that thing… like what I've said you know? Selective memory. What you do with your hands you tend to remember more. In that case this falls under that category.

00:19:58

PRE:

OK. So I have kind of reached the end of my questions but in your opinion what other questions do you think I should have asked you?

VIC:

Can't think of any

PRE:

Any particular insights which you think you can share with us, regarding the Engineering syllabus or the approach to Engineering?

VIC:

Probably a suggestion that I would like to make is … since RP is doing PBL based formats for Science probably they should have like an extra classes for students who are having a hard time to cope or who are struggling to cope. These lessons might probably make it more easier. Probably give them a from the book treatment, you know? Giving them that kind of treatment or finding a different alternative to teach such students.

00:21:10

PRE:

What do you think they should teach in the extra classes?

VIC:

Probably recap. Number one, recap the problems. Number two, go in depth as in how to find each. Because what happens is generally in Polytechnic firstly the lecturers tend to assume that you know this already because you have had four or five years of Secondary school experience I expect you, I assume that you know this already. So they don't tend to cover that portion. So what they do is they straight go to the point instead of doing the long method, they cut, cut, cut and they give the short cut. So students who are very good at Math the minute they see, they know. Ok Faci did this this this, ya ok. Whereas the people who are not so good in the subject when they see they go blank. Then they have to wait. Because of that, those students they know, they go for it, and these students are lagging behind and they have to go and ask the Faci or the lecturer and the lecturer has to explain bit by bit by bit. Ya probably instead of doing that, probably what they could do is add extra classes and they could actually do it step by step. Even though the student knows or does not know they do it step by step, opening up every single way and making it as long and as detailed as possible. So in that way students when they see, ok, they learn.

00:22:39

PRE:

Do you think that these extra classes should come before doing the module, during or after?

VIC:

I think it would be good if it is done before the module. For example in JC they have this three month free thingy that you go and then you get used to the environment and stuff. Poly maybe what RP students should do … in RP's case they could probably open up these extra classes for all these modules and let students go through and then they teach detailed, the long winded way and once they are very good at the long winded way, whatever problem you throw at the student the student would have confidence to solve it. They would be more comfortable for it.

00:23:31

PRE:

Ok. So anything else to tell me? About your views on Engineering. How your views of Engineering have changed?

VIC:

View of Engineering…I would say that if now somebody were to tell me you need Math? Math is very important for Engineering? I will tell him…nonsense. I feel that what we learn in Secondary school we only take like 15% 20% and then you use it you apply in Polytechnic. So the remaining 80% ya it's not I won't say useless. Not relevant…Not totally relevant.

00:24:12

PRE:

So what is very useful for Engineering?

VIC:

The concepts. The way you go about solving a problem. For example simultaneous equations, you find one and then you substitute and then you carry on. In Engineering there are some forms like that. Usually in circuit analysis when you do super position, so if there's two circuits given you short one circuit, you complete one circuit then you come back to the second circuit. In that way, you see there's this similarity.

PRE:

So it's a way of approaching rather than the Maths

VIC:

Ya true

PRE:

Ok. That's all my questions for now, unless you have anything to add?

VIC:

No

PRE:

Ok thanks a lot Vick

00:25:00

End of Interview

Appendix G – Excluded Themes that Do Not Relate to the Core Category