Science and Mathematics Education Centre

A Critical Examination of Electrical Engineering Curricula across Three Institutions in New Zealand

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any person except where due acknowledgement has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Signature:

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Date: May 2009

ABSTRACT

This thesis examines the effect of the curriculum structure on the pass rate of engineering students in three types of institutions in New Zealand; namely, a polytech, a university of technology, and a university.

The pass rate of engineering students has historically been low in all three of these types of institutions. This resulted in the main research question for this study: ‘Is the present engineering curriculum structure in New Zealand the most effective structure in which to prepare engineering graduates for work in the 21st century?’. In order to investigate this question the current curriculum at the above three types of institutions was examined. This examination was undertaken from a number of perspectives. First, the philosophy of an engineering education was determined to establish what exactly an engineering education is. This philosophy was then used to determine which material is legitimate to include in an engineering curriculum and which material should be left out. Second, theories of teaching and learning were examined to determine whether the engineering curriculum is being taught in the most effective way. Third, the theories of curriculum structure and development were studied to determine whether the engineering curriculum is structured in accordance with the latest ideas in curriculum design. Finally, conclusions were drawn about current curriculum structure and whether it complies with modern pedagogical theory.

The two main conclusions that were produced by this study are the following:

- Engineering curricula are designed with almost no regard for the students that are required to undertake them. This is probably the major reason for the high failure rate.
- Understanding in general and engineering understanding in particular are concepts that are not well understood. The result of this is that the teaching, assessing, and curriculum structure for engineering courses are set up using past experience and are not based on any solid foundation. Again, this is an added potential explanation for the high failure rate in engineering.

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CHAPTER 1
INTRODUCTION TO THE STUDY

1.1 Background

The failure rate in electrical engineering courses, in particular in western educational systems, has been a source of concern to engineering educators for many decades. This failure rate manifests itself predominantly in two areas. The first relates to that of first-year engineering students. It is not uncommon for more than fifty percent of a first year electrical engineering (EE) class to fail at least one subject (Henderson, 1997; unpublished statistics for the Manukau Institute of Technology). The second area concerns the time that it takes for engineering students to complete their degrees. Most EE degrees are nominally four years; however, it is rare for engineers to finish their degrees in four years (Schmidt, 2005; Dye, 2005). Based on data collected by Tomkinson, Warner & Renfrew (2002) in the United Kingdom, the average student takes five to six years to finish a typical four-year degree and up to 20% of all students do not complete their degrees at all. In most other areas of human endeavour, such as business, sport, etc., statistics such as these would be regarded as a serious failure and immediate remedial action would be put in place. In addition, an extra year spent at a university or college does not only incur the direct costs of this year to the students, but also results in an opportunity cost to the students equal to their final annual salary at the end of their working career. Based on current engineering salaries this cost is somewhere between NZ$ 80 000 and NZ$ 200 000.

These statistics seem to indicate that there is either something amiss with the structure (curricula) of EE degrees, that there is a problem with the entry conditions for prospective engineers, that the standard of teaching may be low in engineering departments, or that some other problem may exist. However, since most tertiary institutions have strict requirements for students entering engineering degrees (particularly with respect to performance in mathematics and physics) and the fact that the problems mentioned in the above paragraph appear across a range of types of institutions and countries, it is unlikely that the entry requirements or the teaching standards are the problem (Manukau Institute of Technology, 2003). It is therefore more probable that the structure of the EE degrees is the cause of the problem because, for the reasons given in chapter four, the structure of EE degrees is common across many countries and institutions. Therefore, although other possibilities cannot be completely ruled out it is likely that the structure of the EE degrees is the problem. This study will therefore examine, in some detail, all the main aspects of the curriculum: the most likely problem area.

From my own personal experience, of reading engineering to the master’s level and then teaching engineering for over twenty years, I believe that the engineering curriculum contains too much material and that this material is determined by what industry requires rather than by what students can actually deal with in the time available. I further believe that the order in which the material is presented is not effective. It would be better, for example, to introduce particular mathematics concepts when they are needed rather than in year one or two, long before they are used. I believe that by doing this the concepts will have more meaning for the students. This study will examine these ideas in more detail.

1.2 Aim and Research Questions

The aim of this research will therefore be to apply modern theories of teaching and learning in order to answer the key research question, ‘Is the present engineering curriculum structure in New Zealand the most effective structure in which to prepare engineering graduates for work in the 21st century?’

This basic research question will necessarily be constrained by a number of factors. First, an investigation will have to be carried out into the philosophy of engineering education, that is, what *is* an educated engineer? Engineering institutions such as the Institute of Electrical and Electronic Engineers (USA), the Institution of Engineering and Technology (UK), and the Institute of Engineers (Australia) have lists of outcomes that educated engineers are required to meet. These lists will be used to focus this aspect of the research (IET, 2008).

Second, much of modern tertiary education exists within financial and resource constraints that clearly limit what can be achieved in an engineering education program. These constraints will necessarily have to be examined and taken into account in this research.

1.3 Significance of the Study

This study is significant because it is commonly agreed that in a modern technological economy engineering plays a key role. Therefore a study that aims to determine whether the method used to produce engineers is the optimum method will be inherently valuable from a macroeconomic perspective. In addition, at the micro level, a study that aims to reduce the failure rate of individual engineers is important for two reasons. The first is that engineering students that fail are likely to become demotivated and to be lost to engineering (Tomkinson, et al. 2002). This is therefore psychologically damaging to the student and a loss to the greater economy. Second, the opportunity cost, as mentioned above, is significant with the result that one or two years lost through failing at university will be a large cost to an individual student as well as to the profession.

From an educational perspective this study is important because it will examine the engineering curriculum in detail to determine its effectiveness. However, in addition, an important aspect of this study's view of the curriculum is how it is taught and how learning takes place based on the syllabus. This study will also examine these aspects, that is, it will examine historical and modern methods of teaching in order to determine whether the engineering curriculum is being taught in the most effective way. It will also examine historical and modern ideas of learning theory to determine whether the structure of the engineering curriculum is the most effective structure for producing optimum engineering learning.

Finally, this study has personal significance because I am a senior lecturer in a school of electrical engineering and have to deal with significant numbers of students who fail our courses. In addition, the Manukau Institute of Technology has recently re-written all the curricula for its three year bachelor of technology degrees and I was responsible for writing the curricula for eleven of the courses in this degree and shared the responsibility for writing two other courses.

1.4 Overview of the Methodology

In order to critically analyse the EE curricula examined in this study the research will make use, as a frame of reference, the most recently accepted theories about teaching and learning. This process has been attempted in the past; however, it has usually been approached from the perspective of the students, the engineering educators, or employers by using a combination of questionnaires and interviews (As an example of many such studies see Burton, 1998). In my view these studies have not been particularly informative because, first, the students are not educationalists and do not know what educational alternatives are available. They are not, therefore, able to suggest plausible alternatives with the result that most of their suggestions and recommendations can realistically involve only the fine-tuning of existing structures. Second, engineering educators, particularly in universities, are usually not trained in educational theory and rarely have any form of teaching or educational qualification. They are therefore seldom qualified to suggest significant changes to the structure of existing courses (see the Head of Department interviews below). The surveys that have been conducted into employers' requirements also tend to be misleading because most employers have short-term financial considerations upper most in their minds and do not necessarily take a long-term view of engineering education. They tend to require students to be immediately productive and do not value highly the long-term aspects of an engineering education (Henderson, 1997). This often means that employers emphasise the necessity for students to be familiar with the latest technology and minimise the importance of a broad-based and fundamental understanding of engineering concepts.

For these reasons I plan to use an alternative approach that does not involve interviewing or questioning students, engineering educators and employers. Instead, this study will use the latest theories of teaching and learning as an intellectual tool or cognitive map in order to critically analyse existing published EE curricula (Manukau Institute of Technology, 2003). I have chosen EE degrees because EE is my speciality and because the problems with EE degrees seem to be representative of many engineering degrees especially since in most western universities the first year and large portions of the second year are common for all engineering degrees. In other words, the basic curriculum structure of all degrees is similar (UoA, 2003).

The electrical engineering (EE) curricula in New Zealand, South Africa, Australia, and the United Kingdom all comply with the Washington Accord and therefore have not changed very much over the previous decades (Washington Accord, 2003). In addition, because these courses comply with the Accord they are all of four years duration and structured such that the first two years of study are spent on studying mathematics and basic science. It is only in the last two years of a four year program that electrical engineering subjects, per se, are studied (see for example UND, 1995; UoA, 2003; Manukau Institute of Technology, 2003). Further more, from my own personal experience of teaching in polytechs in South Africa, attending universities in South Africa, teaching in polytechs in New Zealand, having a close association with Auckland University (staff at Auckland University moderate some of the subjects I lecture), and having our degree programs monitored by representatives from Woolongong University in Australia it is clear that most engineering courses are presented in a traditional and similar way. That is, the theoretical aspects of engineering courses are presented in a lecture format and these presentations are then reinforced by laboratory work and tutorials.

As mentioned in my thesis proposal I planned to interview the Heads of Department of the three types of tertiary institutions in New Zealand in order to substantiate the comments I have made above and to further justify the methodology adopted in this thesis. The three people that I interviewed were as follows:

1.4.1 The Course Coordinator (PhD Electrical Engineering) for Engineering Systems, at a Large New Zealand University

I was referred to the Course Coordinator (CC) by the Head of Department because he was one of the most experienced lecturers in the Department, he was responsible for the first year Engineering Systems course which currently has about 800 students from all the engineering disciplines enrolled, and he lectured a final year course for the electrical engineers. He, therefore, has had direct experience of the high failure rate of first year students and has had experience of the final year students that have succeeded in completing their degree. This particular CC has since retired from the University.

The CC put the responsibility for passing or failing on the students and did not believe that the method of teaching engineering, the course structure, or the way laboratory exercises were set up was responsible for the high failure rate of first year students. However, he did feel that the large first year classes made it difficult to give all the students the support and attention that they needed. In addition he felt that many students came into engineering without being really motivated and interested in it; that is, they were not "turned on to engineering" and they were not well prepared by the school system for engineering. Finally, he believed that the low overall through-put rate for the degree was primarily due to students not "putting enough effort into the course work" resulting in them taking longer than four years to complete the degree.

1.4.2 The Head of Department (PhD Electrical Engineering) of Electrical Engineering (2005 - 2007), at a New Zealand University of Technology

The Head of Department also put the onus for passing or failing on how hard the students worked and how regularly they attended lectures. He commented that engineering is conceptually difficult and covers too much material. That is, it is outside a student's "domain of comfortable thinking" and it requires a "strong focus from the students" and that it is "heavy on the brain". In addition there are a number of "more exciting", "fun" alternatives available to the students, such as multimedia degrees and IT degrees, which are attracting students away from engineering or acting as a distraction for engineering students. Finally, he added (as I mention in chapter Four) that the basic course structures are determined by the Washington Accord and are therefore difficult to substantially modify; however, he did feel that engineering degrees are becoming too specialised making it difficult for students to change careers later in life. Furthermore, he felt that the engineering degrees are focused too strongly towards post-graduate degrees which means that after four years the students do not have an adequate background to start work in industry making it difficult for a number of new graduates to get employment; that is, the degree is not well "harmonised with industry".

1.4.3 The Head of School (M.E. Electrical Engineering) of Electrical Engineering in a New Zealand Institute of Technology

The Head of School again put the onus for passing or failing onto the students, although he did point out that engineering is conceptually difficult. He did not feel that there was a problem with how engineering is taught or with the structure of the degree. He believed that students that formed study/social groups when they first started at university and supported each other had a better chance of passing than students who worked on their own (This is contrary to my own personal experience. I found it easier to study on my own rather than in a group.).

These interviews revealed that these particular senior academics did not have many enlightening comments about why engineering students do not succeed: they merely blamed various aspects of the students' behaviours. This confirmed for me that the study I am undertaking in this thesis is most necessary and that an alternative methodology to interviews and surveys is necessary. Finally, I have kept the above interviews anonymous because, although I am very grateful to these people for giving me the time and opportunity to interview them and for their candid answers to my questions, I do not wish to cause them any embarrassment due my remarks about their responses.

1.5 Overview of the Thesis

The next chapter, chapter two, investigates the ideal of an educated person in general. This general ideal will then be narrowed down in order to define what it means to be an educated electrical engineer. This definition will then be used in later chapters to evaluate the engineering curricula to establish whether they are likely to produce educated engineers. This chapter is an important starting point for this study because, as will be discussed in chapter four, most modern engineering curricula incorporate significant amounts of 'general studies' or as they are usually termed, 'professional development' courses. The aim of these courses is to give engineers a more general education so that they can function more effectively in a modern society. Chapter two examines the historical and modern ideas of a general education and then using this information, chapter five draws conclusions about whether it is possible to give an engineer a general education in the context of his or her engineering education. In addition, chapter five will use the material from chapter two to determine what general studies should be included in an engineering curriculum.

Chapter three examines historical and modern theories of teaching and learning. This material will be used in chapter five to draw conclusions about how the engineering curriculum should be structured so that it can be taught in the most effective way and so that the most efficacious learning can take place.

Chapter four looks at the historical and modern ideas about structuring the order of studies, that is, curriculum design. Chapter five will use this material to determine the most effective structure for the engineering curriculum. Chapter four also examines the current engineering curriculum and discusses the organisations that determine the current engineering curriculum in most western countries; that is, chapter four will explain that the engineering curriculum is common in most western countries due to the Washington Accord which these countries have signed.

As mentioned above, chapter five uses the material from all the previous chapters to draw conclusions about the engineering curriculum, how it should be taught, and how engineering learning might be best achieved. An important aspect of this chapter is that it will examine how engineering concepts are understood and how understanding takes place in engineering. This is important because engineering studies involve understanding many scientific and mathematical concepts, and therefore the curriculum must be structured so that conceptual understanding takes place.

CHAPTER 2
THE IDEAL OF AN EDUCATED PERSON IN GENERAL

2.1 Introduction

In order to analyse the engineering curriculum it is necessary to understand precisely what an engineering education is, that is, to contextualise engineering education within the general field of education. This is necessary so that a full understanding of engineering education, its area of application, and its limitations may be obtained. To do this it is necessary to establish the aims of education and the definition of an educated person in general and then to compare this general definition with the definition of an educated engineer.

The aims and ideals of education have been contemplated for millennia in many different cultures so, to limit the investigation to a manageable size, only the Western ideals of education will be dealt with. This must not be interpreted as a criticism of non-Western education traditions, such as the ancient and sophisticated traditions in the East and Middle East, or as even a comment on these other traditions … it is merely a practical necessity.

During the past 3000 years some of the greatest minds of the Western tradition have pondered education and the aims of education. Although these people did not carry out formal research, in the modern sense, into educational aims - many of them were highly educated and were educators of one form or another and had extensive practical experience in education. Therefore, it will be instructive to investigate how these great minds viewed education and the aims of education.

In the Western tradition the aims or purposes of education fall into three main categories. One category may be described as education to obtain virtue or the greater good, that is, moral education; the next category may be described as education for universal knowledge and for understanding of the cause of things, that is, a liberal education; and the third category deals with education for power. Each of these major categories has a number of sub-categories as discussed below.

2.2 Moral Education or Education for Virtue and the Greater Good

Aristotle (1952) claimed that the end of everything is the *good* so the first main category that will be dealt with is that of moral education. In fact, Montaigne (1943) stated that knowledge without the knowledge of goodness could be harmful and Tolstoy (1998) felt that one must be able to satisfy one's passions within the limits of virtue. Even Shakespeare commented that one should study philosophy to see how happiness can be achieved through virtue but he warned that one should be careful not become a "stodgy old stoic" (Shakespeare, 1984b, Act i, scene i).

Education for the *good* or moral education develops good habits of will, desire, and emotion, that is, humanity must have knowledge of goodness because, as shown below, many thinkers felt that any other aim of education was pointless. However, a number of questions arise from this conception of moral education (Adler, 1990). For example, should moral education be directed to pleasure and happiness or to duty, that is, to making people kind, courageous, friendly, co-operative, and loyal? Is good character formed by strengthening obedience to the law and moral codes or by habituating people to be moderate and reasonable? Can morality be taught and will someone who knows what is moral and ethical act morally and ethically? These questions are prior to the role of the family and state in moral education and the moralising influence of art, literature, poetry, music, and laws. In addition, moral education has a political aspect, for example, how much state censorship is legitimate and should people with different natural abilities be trained differently? Moral factors also influence the considerations in covered in section 2.3 on *education for knowledge* because moral factors play a role in the pursuit of truth and the learning process. The view one takes of moral education, therefore, affects most aspects of education such as educator training, parental education, and the role of the media. The following sections show how, over the previous three millennia, the great western thinkers have thought about these problems.

As shown below, there is a tension in this category between education for the benefit of the individual and education for the benefit of the state. In addition, many believe that there is a further tension between an education for secular aims and an education for serving god. Each of these sub-categories will be discussed below.

2.2.1 Service to Humanity

Education has been said to be of service to humanity in many ways. In this section the view that education helps one to achieve happiness, to maximise pleasure and minimise pain, to become compassionate, to build character, to develop self-discipline, and to enable one to become a truly responsible person will be discussed.

Plato carried out a thorough investigation of educational aims in his dialogues: in particular, in Protagoras, in the Republic, and in the Laws (Plato, 1875.). In Plato's view one of the major aims of education is the acquisition of virtue. His four virtues were courage, temperance, wisdom, and justice but included concepts such as honouring the gods, honouring one's parents, valuing friendship, not loving money and gifts, and not lying. He claimed that educated people love what they should love and hate what they should hate. In other words, an educated person knows what is good in art, music, morals, et cetera. However, as Plato's dialogs show it is difficult to unambiguously define virtue and the *good*, which in turn makes it difficult to structure education to educate people about virtue.

Aristotle (1952) developed a circular argument involving the good. He believed that happiness is a cause of good and is therefore a *first principle* because it is a cause. However, he also stated that happiness is the realization and perfect exercise of virtue (that is, how one *uses* what one has is important: not *what* one has). In order to achieve happiness or well being, therefore, an educated person will know how (a) to make the right choice of the end and aim of action, and (b) be able to discover which actions produce the right ends. Aristotle felt that education was a personal process that comes from within and to be meaningful one must do it for oneself, or for one's friends, or for excellence; education cannot be externally imposed on one.

Interestingly, Epictetus's (1990) views on education were a precursor to many of the modern theories on education that emphasise the importance of prior knowledge. His experience showed that education is learning to adapt precognition to particular instances and to see that some things are in one's power and some are not. He added that one can depend only on the will and acts of the will - therefore the *good* must be connected with the will. This view inturn directly influences one's happiness because if one is unhappy it is one's own fault since we all have the potential to be happy. He added that one of the main causes of unhappiness was having many possessions because one can be externally controlled only if one has possessions. That is, education teaches one to perform the acts of a wise and good person and not to put any store in possessions but to have affection for all humankind and treat the whole world as home. Therefore, if one wishes to be free from grief, to not be disturbed by daily life, to not be humbled, and to be free one must give up things that do not depend on the will. If one envies what others have it means that one is not contented with what one has and one should change what one has or re-evaluate one's values. Epictetus noted that an educated person can distinguish between appearance and reality and considers what has happened in the past, what is likely to happen in the future, and then acts. He added that if one does not understand a complex matter then others would not accept one's criticism or praise or judgement on the matter. It is therefore important that one has the correct opinions and interprets appearances properly. He recommended that common opinion should be taken as a guide.

Aurelius (1990) noted that the universe is undergoing constant transformation and that most of life is based on opinion therefore the aim of education should be to give one principles that are brief and fundamental.

Montaigne's (1943) view was similar to Epictetus's in that he felt that the aim of education was to get to know humankind so that one could embrace the universe as one's "city" and distribute one's knowledge, company, and affections to all humanity. He felt that most people were much too parochial in their outlook. In addition, education should teach one to regulate one's behaviour, to regulate one's sense, to know oneself, to learn to live and die well. Also, one must know what valour, temperance, and justice are and know the differences between ambition and avarice, servitude and submission, and licence and liberty. One should know what true contentment is and know how much one should fear death, pain, and shame. That is, in Montaigne's view the studying of philosophy is crucial to becoming an educated person. He stated that philosophy has virtue as its aim, and even the young can master the philosophy of virtue particularly since, in his view, virtue's tool is moderation not strength. A virtuous person, therefore, will know how to deal with fortune and misfortune. However, he was of the opinion that character and understanding are more important than raw learning, that is, being an able person is more important than being a learned person. Therefore, one's education, work, and study should aim at forming judgement, that is, judgement based on understanding. However, a person may be wise without ostentation and without arousing envy, that is, one should use wisdom to correct oneself rather than to correct others. Montaigne believed that the surest sign of wisdom is constant cheerfulness and that one should wish to do no evil even if one knows how and one should be able to fit in with present company even if it means going to excess at times, for example, by occasionally drinking too excess. He stated that an educated person "makes his learning not a display of knowledge, but the law of his life; who obeys himself and submits to his own injunctions" (Montaigne, 1943, essay #26).

Hume (1748) saw a balanced education as being the most valuable and of the greatest efficacy for the individual and humankind in general. He felt that there are two approaches to the philosophy of morals: the first considers *mankind as the basis for action* (one follows one's heart) and it is influenced by taste and sentiment to become virtuous because of the happiness and glory that virtue brings, that is, one feels the difference between vice and virtue via poetry, eloquence, et cetera. Therefore, in Hume's view, an educated person is one who in his heart loves probity and honour. The second considers people as *reasonable beings* and endeavours to form their understanding more than cultivate their manners. The second seeks the ultimate truth, that is, the formation of morals, reasoning, and criticism. Most people live their lives by following their heart rather than by cold logic. Philosophers of the first kind are seen by the masses to be following common sense and therefore if they err they can easily recover from their errors whereas the second type is seen as recondite and if they err, their whole logical edifice can be destroyed. The most perfect character is supposed to be between one with bookish theoretical philosophy and the mere ignorant - that is, one must have an equal taste for books, company, and business. Hume felt that nature seems to be indicating that people must be sociable as well as reasoning beings; they are also active beings and therefore should have an occupation (be involved in business); they also need some relaxation; therefore a mixed life is most suitable. He felt that one should be a philosopher but above all be a person because the life of a pure philosopher is difficult.

In Mill's view (1990a), people should be educated to value individuality, individual liberty, and diversity. He felt that people who have strong desires and natural impulses could, with the correct nurturing, become the most valuable members of society. Modern humanity has conformed too much to accepted behaviour (political correctness) and custom (fashion). Mill claimed that a satisfied life depends on having tranquillity *and* excitement. He was of the view that life appears to have no value when one cares *only* for oneself. In addition, a lack of mental cultivation makes life unsatisfactory because a cultivated mind finds interest in everything around it. Genuine private affections and a sincere interest in the public good are possible to every rightly brought up human being. In turn, a rightly brought up person, who is not oppressed, will find an enviable existence and, in addition, the major evils of life would be gradually reduced, that is, disease, poverty, and many things often attributed to bad fortune. Mill felt that everyone should be educated so that they could take pleasure in the right things, that is, things that would spread social advantages widely in society and would raise the standards of life generally (morals and material wealth). Once introduced to reading and learning people would not return to their uneducated ways; they would pursue higher things (politics, morality, et cetera). *Therefore, according to Mill what is taught is not so important as long as everyone is educated.* He added that the state should ensure that everyone can read, write, and calculate but should not itself provide the education but make it illegal for anyone to go uneducated. The state should monitor a school's performance and subsidise the poor. In addition, schools should be free to undertake educational experiments (Gregory, 1989).

As discussed in Nash (2003), Buber, who expressed an existentialist view of education, stated that humankind used principles and traditions as checks and reminders, not as infallible guides. Values are created in the here and now and are manifest as one relates to others, that is, each person is unique. Responsibility is important for Buber, that is, responsibility to others and therefore dialog is important, that is, an educated person can listen as well as talk. Real dialog depends on authenticity and therefore one must be oneself in relationships. Buber felt there was continuity between learning and life and therefore knowledge for its own sake should not be encouraged. For Buber, an educated person was not one who merely had had his cognitive faculties trained but one whose inmost spirit had been infused by what he had learned.

2.2.2 Service to the State

Education is a political issue because it is an expression of values and therefore the subjects taught, how they are taught, where they are taught, which children are taught, and the extent to which education is equal for all are all political questions (Gregory, 1989). Brain manipulation with drugs and brain manipulation via education have similar ethical issues, in particular, the question of what the manipulator's motives are. The only real difference is that manipulation through drugs can be impersonal whereas manipulation via education has to be personal (Gregory, 1989). Hence, a number of questions arise regarding the role of the state in education (Adler, 1990). Should education be publicly or privately run? Should different groups of people be educated differently and should there be any form of affirmative action? Should the state direct education to its own welfare or to the individual's welfare or to the welfare of god? Should education preserve the existing culture or promote a better and higher culture? How much freedom should be given to educators? To what age should citizens be educated? Should politicians or should educators determine the aims of education? (This last question is easy to respond to in the context of a democracy because politicians are the representatives of the people and therefore should determine the aims of education. Educators do not have a mandate from the people and therefore have no right to determine educational policy; they may act only as advisors to politicians but the politicians must determine the policy (Honderich, 1995)).

A view of education that is prevalent among some educational thinkers is that rather than an equal education for all, an education that provides for each person's autonomy and citizenship requirements is preferable. Once these basic needs have been met then wide differences in higher education could exist (Honderich, 1995). Nevertheless, educators differ in their conceptions of the boundaries of formal education. Children have to go to school by law in most countries and are therefore a captive audience so care must be exercised with what is taught. Children are not well equipped to handle severe educational bias. However, on the other hand, care must be taken to ensure that schools do not become boring, uniform, and lacking in the teaching of anything controversial (Nash, 2003)

In agreement with the above two paragraphs, Aristotle (1952) believed that politics is the "master art" because the legislation made by politicians is for a state's good so in this section the idea that the aim of education is to be of service to the state will be discussed. In other words, education must be used to mould citizens so that they suit the form of government under which they live so that they accept and function well in the political system under which they are being governed. He stated that to speak well on public affairs it is necessary to understand all forms of government and their customs, institutions and interests. He added that this knowledge coupled with the fact that most people want to maintain the established order and if the people believe the leaders have their interests at heart they will be easier to persuade and govern. In Western society this means learning to accept democracy as the most efficacious political system. Education in a Western democracy, under this view, must then be used to educate people to accept democracy, to understand democracy, and to function well in a just non-corrupt democratic state. It is interesting to note that even a great thinker like Hobbes (1990) did not view democracy as the ideal and took an extreme view, which was prevalent in his time, that the people must be taught to accept the absolute rights of their sovereign governing body. In fact, he added that the reading of books about popular government is dangerous for sovereign governments.

Plato (1875) claimed that if and only if everyone is virtuous then each person has the right to express political opinions. That is, in his experience, education makes the members of a society and of a state good. It makes these members want to be good citizens and teaches them how to lead (rule) and how to follow (obey). Many centuries later Adam Smith (1990) agreed with this concept when he stated that an instructed and intelligent people are usually more decent and orderly than an ignorant and stupid one and that they are more difficult to mislead, which is of particular importance in a free state.

In Plato's (1875) experience one would be trusted to take charge of something or of a situation, that is, become a leader and be allowed to deal freely with it and to take charge of others when one has the wisdom to do so. When one does not understand something one is not morally free to deal with it and, usually, one will be prevented from doing so by society, society's laws, et cetera. A wise knowledgeable person is useful to society and needed by society but an uneducated person is usually of little use to society ; in fact, to be a good leader wisdom and knowledge are essential and a person without education is "lame" (Plato, 1875, p. 322). A true leader (guardian, ruler) must know, be able to interpret, and be able to articulate what the good (virtue) is in each thing that he or she deals with, that is, he or she will know its true essence. This means that only the properly educated can become true leaders (rulers). Plato did not believe in the individual pursuing his or her own tastes and interests (Honderich, 1995). He believed that each person should play a destined role in society so that the good of the external society is achieved. Rulers must have the wisdom to guide others and most people should be trained in the trades and be taught reading, writing, calculating, and trade skills (a situation that many would argue prevails currently). The brave and gentle would be chosen as soldiers (guardians) and they would be educated in music, literature, and gymnastics. The most steadfast, selfless soldiers would be trained to be rulers, that is, they must become lovers of wisdom (philosophers) skilled in science and reasoning. Guardians and rulers would live communally, have no possessions, and have communal wives and children. There would be no discrimination between women and men. The guardians and rulers would philosophise for the general good and not for their individual good. Therefore, education would be used to segregate society and philosophers (those who understand the Platonic forms) would rule (Honderich, 1995). Plato gave greater prestige to the study of ideas rather than practical studies and manual work. This prestige resulted in the modern split of liberal arts for leaders and vocational studies for followers (Nash, 2003). In summary, Plato's main themes are the following:

- Education and individual lives are for the state.
- Education is for building character not just intelligence.
- Education can transform individuals so that they accept his communal ideas.
- He does not accept the democratisation of education or the idea of child centred education.
- Education cannot proceed based on the current interests of the young; instead, the young must be led by their elders.
- He did not accept pluralism … wisdom is fixed and one (Honderich, 1995).

Cervantes (1949) saw the aim of education and human knowledge to be of service to the state in two main areas. The first was to administer distributive justice, that is, to give each his due and to see that good laws are observed. The second was to use and train warriors to obtain peace. He viewed peace as the greatest good.

Swift (1990) had similar views to Cervantes because he stated that if each person in a state lives a life of reason there will be no evil in that society, that is, what cannot be dealt with by reason is not known. Therefore, education must be guided solely by reason.

Dewey, discussed in Honderich (1995), saw education as having overarching political aims. He combines child-centeredness and hostility to traditional learning with pragmatic socialism. *He linked education to a child's attempt to solve problems arising from its own social experience.* He said, "The full meaning of studies is secured only when they become integral parts of the child's conduct and character … as organic parts of his present needs and aims – which in turn are social" (Honderich, 1995, p. 213). In his view, traditional education produced only, "barren symbols and flat residues of real knowledge and it perpetuates elitism and social division" (Honderich, 1995, p. 213). According to Dewey a person is formed through interaction with the natural environment and social environment, that is, the individual and society have meaning only through each other. An educated person is one that is reflective, critical of authority, and of custom and tradition as the determinant of belief and action. He prefers scientific methods to solve problems. (This pragmatist view is also associated with Pierce and James (Nash, 2003)).

Skinner (1973) rejects the model of person as a free agent who acts in accordance with the decisions of an inner self that is neither fully explicable nor fully controllable by scientific means. He envisages the use of scientific knowledge about the control of human behaviour to create a "planned man", that is, one who will be conditioned to behave in the way best calculated to achieve society's goals. Behavioural engineering will remove all of man's antisocial tendencies and he will want what is good for him and society. Skinner influenced the development of programmed instruction using teaching technology (machines) and behavioural outcomes in education. *He believed that there is no alternative to the control of human behaviour but only alternatives for who is in control.* Not to use scientific methods to control human behaviour is, for Skinner, irresponsible. Skinner advocates using scientific control to produce a society in which it is easy to be good and an educational system in which it is easy to be excellent. According to Nash (2003), one of Skinner's most important contributions to education was to influence educationalists to investigate all aspects of control in education.

2.2.3 Service to God and the Contemplation of God

This section deals with education in a religious context, that is, education is both moral and intellectual with god as its primary source and the church as an intermediary (Adler, 1990).

As discussed in Nash (2003) Aquinas tried to synthesize reason and faith. He, however, believed the products of faith were superior because they had access to divine truth which reason does not. Hence, Aquinas used divine revelation as his starting point. In his view an educated person, therefore, is the Scholastic, that is, "[a] man whose rational intelligence had been vigorously disciplined for the pursuit of moral excellence and whose highest happiness was found in contemplation of the Christian God" (Nash, 2003). Aquinas's ideas formed the basis of Catholic Theology and fostered the idea of intellectual discipline in the West. Aquinas thought an educated person was one capable of self-learning however, the Catholic Church has always emphasised the importance of the educator.

St. Augustine (1961) had a clear view of the aim of education and learning; it was to be of service to god because he believed that god was the source of all truth and one must open oneself to his divine input but with the aid of a teacher. He added that reading learned books is of no value if one is lost in the doctrine of love given by god. He was of the view that less learned and intelligent people can be better off than the learned if they do not forsake god. In addition, he felt that if one is, "to share the truth [the mind] must be illumined by another light [god], because the mind itself is not the essence of truth" (Augustine, 1961, p.15). That is, one needs to listen to the heart not the head because god cannot be understood in physical or logical terms and all truth comes ultimately from god.

Interestingly Lucretius (1968) did not see education as a service to god but took the contrary view that philosophers were important to humankind because, among other things, they would aid one to minimise the influence of the gods on one's life and decisions.

2.2.4 Transmission of Cultural Heritage

Friedrich Nietzsche (2003) in his series of five lectures entitled *The Future of our Educational Institutions* saw the transmission of cultural heritage as being a major aim of education. In these lectures Nietzsche stated that one should use rational thought to determine right and wrong bearing in mind the wisdom of ancient Greece; that is, one should question whether what one knows is true and valuable or merely a mask for power relations (Also mentioned in Honderich, 1995). He felt that much of modern culture was superficial and that "real" culture is understood by only a few people. In fact, he saw modern education as useless because it did not make students cultured and it was merely aimed at maximising material gain in as short a time as possible and for states to maintain their power. If any culture is taught it is only culture that is compatible with gain and, in addition, most students overspecialise. For example, he stated that:

> For the study of science has been extended to such interminable lengths that he who, though not exceptionally gifted, yet possesses fair abilities, will need to devote himself exclusively to one branch and ignore all others if he ever wishes to achieve anything in his work. Should he then elevate himself above the herd by means of his speciality, he still remains one of them in regard to all else, … that is to say, in regard to all the most important things in life. Thus, a specialist in science gets to resemble nothing so much as a factory workman who spends his whole life in turning one particular screw or handle on a certain instrument or machine, at which occupation he acquires the most consummate skill (p. 13).

Nietzsche believed that a person's mother tongue was the starting point for getting to grips with one's culture, that is, one should become as competent in one's own language as possible, and he regarded a contact with nature as important spur to culture. In addition, he felt that only a few geniuses are capable of a true higher education and that the rest of the herd must show obeisance to these geniuses and be led by them. In turn, this means that there are few educators capable of teaching these geniuses. The net result is that modern society tends to hamstring geniuses; however, fortunately due to the nature of genius, most of them will create anyway. The following quotes from Nietzsche's lectures are instructive:

> All culture begins with the very opposite of that which is now so highly esteemed as "academical (sic) freedom": with obedience, with subordination, with discipline, with subjection. And as leaders must have followers so also must the followers have a leader … here a certain reciprocal predisposition prevails in the hierarchy of spirits: yea, a kind of pre-established harmony. This eternal hierarchy, towards which all things naturally tend, is always threatened by that pseudo-culture which now sits on the throne of the present. It endeavours either to bring the leaders down to the level of its own servitude or else to cast them out altogether. It seduces the followers when they are seeking their predestined leader, and overcomes them by the fumes of its narcotics (p. 63).

> … then you too will feel what a pre-established harmony there is between leader and followers, and how in this hierarchy of spirits everything impels us towards the establishment of a like organisation. You can divine from my simile what I would understand by a true educational institution, and why I am very far from recognising one in the present type of university (p. 64).

A number of thinkers had similar ideas to Nietzsche, for example, Honderich (1995) mentioned that Mathew Arnold and Cardinal Newman both promoted the classics in education and Schiller valued an aesthetic education**.** Honderich also notes that Coleridge had similar ideas to Nietzsche in that he believed that an educated elite would "leaven" the rest of society. However, Cardinal Newman did insist on a rounded education to produce a wide view of existence.

2.3 A Liberal Education or an Education for Universal Knowledge and an Understanding of the Cause of Things

The second major aim of education, as this section will show, is that education should be used to obtain knowledge and to understand the world around us rather than basing our view of the world on superstition and mysterious beliefs.

Adler (1990) notes that in a liberal education humanity is treated as an end and not as a means. Liberal education is directed at living well (in the real sense) and for one's own sake and for one's friends' sake and for the pursuit of excellence. Education to earn a living, or to provide material gain for others, or so that someone can be "put to use" is not liberal, that is, any learning that does not make one better suited to the practice of virtue is not liberal learning. He adds that in a more restricted sense, a liberal education is directed at improving the mind through the acquisition of knowledge and skills, that is, it is the opposite of servile training and is directed at developing good habits of thinking and knowing.

Honderich (1995) states that Aristotle shared Plato's distrust of educators who were afraid to appear despotic and he saw the gaining of knowledge by individuals as a justified end in itself; that is, knowledge is not only for the state. In fact, Aristotle (1952) believed that a wise man is one who knows the causes of things and has universal knowledge implying that, for him, these concepts are an important aim of education. However, he valued experience and was of the view that people of experience succeed better than those that have theory without experience.

2.3.1 Transmission of Established Truths

As Honderich (2003) noted, St. Augustine believed that education is the transmission of established, revealed truths that lead to salvation and up to the 17th century education consisted of imparting to the young what *had* already been learnt.

2.3.2 Judgement, Wisdom and Foresight

Aristotle (1952) was of the opinion that an educated person should be able to form a fair off-hand judgement as to the goodness or badness of the *method* used by a person trying to justify an intellectual position on some topic and should be able to make these judgements on method in all fields of knowledge. This does not mean that each person has to be an expert in every field however it does mean that we all should be able to pass judgement on the *methodology* used by someone trying to establish facts; that is, everyone should have a working knowledge of logic and rhetoric.

Descartes stated that, "the end of study should be to direct the mind towards the enunciation of sound and correct judgement on *all* matters that come before it" (Descartes, 1969b, Rule i).

Kant's (1990c) view was more specific than that of Descartes' because he stated that one must not merely teach youth a list of dogmas but must rather teach them *how* to think. His experience indicated that parents should give their children a varied education because they (the parents) do not know what the future holds. Children must learn how to determine the value of whatever they are doing or experiencing with the ultimate aim of rational beings being happiness. Kant extended this concept by stating that one needs reason and philosophy to counteract our desires and to help one to follow his universal rule. He stated this rule as follows: "I am never to act otherwise than so that I could also will that my maxim should become universal law" (Kant, 1990b, p. 268). He was of the view, therefore, that philosophy should be used only to render a system of morals more complete and intelligible. The universal rule, however, comes from common sense and not from complex theoretical philosophy. The universal moral law is prior to any determining principle for the will such as the *summum bonum*.

Montaigne (1943) agreed with the above commentators but had a jaundiced view of pure book learning. He stated that education should make one good and wise rather than learned and felt that many educational books are chosen because they are well written rather than because their content is worthwhile, that is, a good education should fundamentally change one's judgement and conduct. Montaigne quoted Lactantius as saying, "The common people are wiser, because they are as wise as they need be" (Montaigne, 1943, essay #17). Montaigne saw education as giving one the abilities of notable people such as military ability, virtue, the knowledge of poetry, the ability to die a good death, gentleness, affability, sincerity, firmness of character, and valour. He further noted that, obviously, ignorance exists when one has no knowledge; however, it also exists in many that have doctoral knowledge. Simple peasants are often good people, as are *true* educated philosophers. It is the "in-between" people who are dangerous, inept, and importunate; they trouble the world. In addition he felt that the ability to judge, reason, and know does not seem to have brought humanity much advantage over the animals, that is, a wise person knows the true value of things and there are probably more good people (judging by actions and conduct) among the ignorant than among the learned. Therefore, humanity needs laws because if it were left to its own devices it would degenerate into savagery. Montaigne concluded by stating that one should abandon solicitude for outside things and avoid servitude and obligation; in addition, he felt that solitude is also important. He felt that learning is like all "goods" because it has, "much intrinsic and natural vanity and weakness and it costs dear" (Montaigne, 1943, essay #12). That is, some learning hampers and burdens us instead of feeding us; instead of curing it poisons us.

In slightly more recent times William James (1890) was of the view that being able to bring back a wandering attention is the root of judgement, character, and will. An education that provides the above is an education par excellence but it is difficult to know how to implement such an education.

2.3.3 Learning for Learning's Sake

Milton (1990) summarised the views put forward in this subsection when he stated that one should love learning for itself in the service of truth.

Descartes' (1969b) view of learning was that it is important to gain a good overall understanding or universal wisdom; in fact, all other studies are useful only because they contribute to this. Hence, one must keep looking at the big picture. People who have over specialised often (unwittingly) leave out facts that may be important in the overall picture. All the sciences (knowledge) are interconnected and should be studied together and not be isolated from each other. By studying all knowledge, one will ultimately make more progress in specialist areas than the specialists will.

Kant (1990c) also saw the value of learning for learning's sake because everything comes to us via our senses therefore we can never "know objects as *things-in-themselves* but only as appearances" (Kant, 1990c, p 337). These appearances are always only of the “conditioned and conditions” but one wants, if possible, to discover what things are in-themselves for the supreme or perfect good, that is, so that we can live by reason (Kant, 1990c, p. 337). According to Kant, philosophy is a love of wisdom but it is also a search for the greater good. That is, a philosopher is a “master in the knowledge of wisdom”, and therefore no one is truly a philosopher but merely strives in this direction (Kant, 1990c, p. 338). As an example, Kant was of the view that sophisticated proofs of the existence of god will never mean much for the average person and that one must decide whether a proof of god’s existence is to get at the truth or to provide a practical basis for religion.

These ideas were further emphasised by Hegel when he stated that, “[the] growth of universality of thought is the absolute value of education” (Hegel, 1967, Para. 19). That is, education should move one from selfish individual thought and a state of nature to a more communal way of thinking. He added that, “The uneducated man allows himself to be constrained in everything by brute force and natural factors …. The educated man, however, develops an inner life and wills that he himself shall be in everything he does” (Hegel, 1967, Para. 63). Therefore, educated people’s behaviour is governed by the universal characteristics of a situation and they do not allow their personal idiosyncrasies to obtrude. Uneducated people allow their personal idiosyncrasies to obtrude in all they do and they are likely to hurt the feelings of their neighbours.

Alfred North Whitehead (1911) illustrates the value of knowledge for knowledge’s sake by discussing how, for more than a thousand years, the study of conic sections was undertaken purely as an abstract science before it was discovered to be of pivotal importance in many practical laws of nature: in particular in the study of planetary motion. The theory of conic sections illustrates how knowledge and research should not only be confined to the immediately useful. Knowledge for knowledge’s sake must never be under estimated. There are many examples to show that excessive specialisation is not the most fruitful way to discover new knowledge. Novel ideas are more likely to spring from an assortment of knowledge and a thorough conception of the methods and ideas of distinct lines of thought. A modern illustration of a similar idea, in the technological field, is that of the invention of the laser ("An unexpectedly bright idea", 2005). Initially the laser was merely a technical curiosity but has developed into one of the central technological elements in the post-modern digital age.

To conclude this section George Eliot (1990) noted that knowledge is the only route to filling ones life with action that is rational and ardent.

2.3.4 Ability to Self-learn

Gibbon illustrates the theme of this section when he states that, "a man of learning multiples his own experience by reading and reflection", whereas someone who does not read is limited to his own experiences that, in a relatively short lifespan, are necessarily limited (Gibbon, 1776, chap. ix).

Froebel saw humanity as essentially good. He regarded self-contemplation and self-education as essential for all. He believed that people develop via a creative struggle with the environment, that is, "Everything has a purpose, which is to realise its essence, the divine nature developing within it, and so to reveal god in the transitory world" (quoted in Gregory, 1989, p. 279).

2.3.5 Gain real Self-awareness and get to know One's Ignorance

Spinoza stated that, "To perfect the intellect is nothing but to understand God" (Spinoza, 1923, appendix viii). That is, humanity must adequately (correctly) conceive itself and all other things. He concluded that one must educate humanity so that it lives under the direct authority of reason and that one must learn to teach virtues and not just denounce vices.

John Locke (1690) extended Spinoza's ideas by noting that the fundamental principles of knowledge are difficult to develop because the word of god is in words of uncertain meaning and that innate principles may become corrupted and that there are contrary principles in different cultures. He added that many basic principles are obtained by osmosis from adults and peers, that is, most are unexamined and concluded that one needs leisure time so that one can examine one's fundamental principles. He emphasized the moral aspects of education at the expense of the intellectual and scientific. Locke promoted the classical liberal defence of individual freedom against the authorities of the state and the church. He saw science, reason, and experience as the best safeguards against unreflective stagnation and enthusiastic radicalism. Locke combined the idea of the English gentleman with democratic puritan ideals and practical characteristics. He believed the mind started as a "tabula rasa" and therefore experience and sense perception are important in education. This implied that education must be heavily experiential and aimed at producing virtue, wisdom, breeding, and learning. Locke's puritan ideals greatly influenced American educational ideals (Nash, 2003). Finally, his approach to teaching is summarised in the following quote: "We should, in educating children, strive to prevent the undue connection of ideas that are in themselves loose and independent of one another" (quoted in Gregory, 1989, p. 440).

Descartes cautioned that, "Only those objects should engage our attention, to the sure and indubitable knowledge of which our mental powers seem to be adequate". He added that, "Science in its entirety is true and evident cognition" (Descartes, 1969a, Part i). Therefore, one should not get involved in things beyond one's capabilities because one is just likely to form useless opinions and, in fact, there are few things that we can have sure and indubitable knowledge of.

Goethe took and extreme view of learning in his poem *Faust* when he has Faust complaining that one learns nothing from book study and that "ignorance is our fate" and all teaching is "empty" (Goethe, 1959, p. 1). Faust continues that only the ignorant are fascinated by learning and that life teaches one to long for death. He adds that real knowledge cannot be taught and that a free mind and nature turn one into an atheist, that is, educators learn and teach inanities.

Swift (1990) added another slant to this section when he noted that one often used the "freak of nature" explanation to explain something one does not understand.

In the last sentence of his Tractatus Logico-Philosophicus Wittgenstein (2004) summarised how we should view our own knowledge and how one should approach much of what the western world has regarded as knowledge when he stated that, "Wovon man nicht sprechen kann, darüber muβ man schweigen".

2.4 Education for Power

2.4.1 Financial Gain

As this section shows, a number of commentators have expressed the idea that financial gain should be the main or at least an important aim of education.

Aristophanes (1973) carried out one of the first investigations into the aims of education in his ironic play The Clouds. In this play he showed how education is often used for financial gain, for example, by winning legal arguments, rather than for trying to get to the truth. The play ends by showing the detrimental outcomes, such as a son turning on a father, that will result if the wrong aims are adopted for education. In fact, Aristotle (1952) went so far as to state that paid employment absorbs and degrades the mind (a view that I have a lot of sympathy with). He added that "seeking after the useful does not become free and exalted souls", and that one works in order to get leisure, implying that an aim of education should be to enable one to use one's leisure well (Aristotle, 1952, p. 1331).

Montaigne's (1943) experience indicated that learning was being maintained in the modern world only because it was needed in the professions such as jurisprudence, medicine, teaching, and theology. Without this professional need he was of the view that learning would disappear. He went further by stating that an unworthy aim of learning is learning for gain because it "looks to others and depends on them" (Montaigne, 1943, essay #26). In addition, he felt that commercial interests or power interests often distort the truth. Descartes (1969a) extended this idea when he stated that life had taught him that glory and wealth could be achieved with counterfeit reasoning and vulgar understanding.

In his great novel War and Peace Tolstoy (1998) listed the aims of Masonic education as follows: (a) the dissemination of pure truth and to secure the triumph of virtue, (b) to cleanse people from prejudice and unite with the wise, (c) to overcome superstition, infidelity and folly, (d) to form united organisations of authority and power, (e) to ensure honest people are rewarded, and (f) to not use violence to achieve the above but punish vice and patronise talent and virtue. The key item of which is probably to form organisations of power and authority.

2.4.2 Cure Alienation and De-humanisation of Humanity by Capitalism

Marx (1990) expresses the idea of alienation and de-humanisation most eloquently. He states that a peasant artisan can, independently of a factory and capital, exercise knowledge, judgement, and the will; however, a factory worker is useless outside of a factory. A man or woman of knowledge and a productive labourer become more and more separated in the modern capitalist world. Marx quotes Adam Smith as saying, "The man whose whole life is spent in performing a few simple operations ... has no occasion to exert his understanding .... He generally becomes as stupid and ignorant as it is possible for a human creature to become" (Marx, 1990, Para. 5). In Marx's view, a major cause of the above is the division of labour, that is, specialisation. Marx's (and Engel's) main concern, therefore, was to cure the alienation and dehumanisation of humanity by the forces of capitalism. He saw the material dimension of history as primary and economic production, which was the basis of life and ideas (religious, educational, and political), was determined by the structure of society. The ruling class were the ones who controlled the means of material production and therefore society's structure. Hence, Marx believed that the *hidden interest behind and idea is found from its social function not its intellectual content.* The only way to change society is by revolution and humanity will only mature once autonomous, socially responsible people draw together voluntarily in community. Marx's educated person is not an individualist or coerced collectivist but an accountable communal person who obtains freedom via social relationships because individual freedom requires social authority. As Nash (2003) notes, with reference to Marx, state intervention is necessary to remove gross inequalities and expand opportunities but ultimately the individual is responsible for human regeneration. Marx was of the view that the concept of teaching entailed the domination of one class over another and the perpetuation of a bourgeois value system, for example, the reading of books that were produced predominantly by the middle class. Gregory (1989) notes that Marxist education linked education with practice and was overtly political in its aims, that is, a part of the class war.

In his discussion of Makarenko, Gregory (1985) notes that Makarenko was not impressed by the humanist views of thinkers like Rousseau which he felt did not apply to the poor masses. He realised that children's basic necessity was security and saw the collective (communism) as giving security to the individual and a sense of obligation to others. An individual must be incorporated into the collective in such a way that he feels he belongs to it freely and without compulsion. Self-discipline is the goal of moral education but the educator is responsible for developing it. Children learn by being given responsibility. Cultural activities as well as normal work were important for human development. School is more than just a place where knowledge and skills were acquired but was a way of life were one learned initiative, self-respect, et cetera, by working together and through self-government. Respect for the individual is an essential requirement of this approach. Makarenko challenged his pupils with difficulties to overcome, that is, to prepare them for life. He tried to maintain a balance between kindness and severity with his pupils and he avoided sentimentality.

2.4.3 Learn in order to Do

In the Western tradition learning a manual skill has usually not been regarded as education, for example, Plato (1875) did not regard vocational training as education. He stated that one should clearly distinguish between education and training -

however, he was of the view that a person could become really good at only *one* thing by practising that *one* thing. The more advanced the one thing the more time, skill, art, and application plus natural aptitude and "spirit" is required in order to master it. However, Aristotle (1952) had a different view because he stated that an educated person is one who is able to do what he or she wants with the material available.

Bacon (1990a) was of the opinion that all of practical life should be "drawn and collected into contemplation" (p.11), that is, the making of one's fortune should not be the aim of one's life and learning but it is still worthy of study. In addition, he dismissed past authority and put more emphasis on individual experience, that is, the individual must engage in pre-suppositionless observation. However, as Honderich (1995) noted, his philosophy had little influence on how education was practiced until the 19th century because up to then it merely followed traditional lines ignoring his ideas.

Marx quotes Hegel as saying that, "By well educated men we understand, in the first instance, those who can do everything that others do" (Marx, 1990, chap. xiv). Weber (1946) in a vaguely similar vein states that in the modern world an educated person is one who has useful (expert) knowledge; in times past an educated person was one who was chivalrous or ascetic or literary as in China, or a gymnastic humanist as in Hellas, or a "conventional man" as in Anglo Saxon countries. He adds that some peoples also valued special military, judicial, or theological knowledge in times past.

Bacon (1990a) agreed with the above ideas when he noted that learning should be for doing things but that philosophy and the arts should not be neglected because they are like the stomach in that they digest knowledge and distribute it (to humanity) but do not perform any external action or have any sensory function. He added that philosophers of old often erred on the side of a quite serene contented life rather than searching for short intense experiences which usually involve *doing*.

2.5 Physical Hardening

A number of thinkers, such as Plato, saw physical conditioning of the youth as a major element in education however, since this study deals predominantly with the education of adults, this aspect of education will not be discussed.

2.6 The Disadvantages of Being Educated

Bacon (1990a) wrote an interesting essay entitled, “Advancement of Learning”, on education and learning which highlighted the advantages of learning by rebutting the common arguments put forward against learning. These arguments and the rebuttals are summarised in what follows:

One needs to overcome the many popular negative ideas about learning. Many feel knowledge is dangerous, that it makes one sad and anxious, and produces atheists. Bacon countered this by noting that humanity’s fall (Adam and Eve) was due to gaining the knowledge of good and evil and making its own laws and ignoring god’s law, it was not due to getting knowledge about nature. By getting the knowledge of good and evil humanity assumed god was not the origin of this knowledge and therefore god was not needed and humanity could stand on his own feet. One cannot have too much knowledge but one can have the wrong type of knowledge, that is, one must couple charity (the good for humanity), with knowledge. The search for knowledge is acceptable if, (a) one does not base one’s happiness on knowledge and forget one’s mortality, (b) apply knowledge to give contentment and not angst and ostentation, that is, keep emotions out of knowledge, and (c) don’t try to discover the mysteries of god. Sensible and material knowledge will not give an individual perfect knowledge. However, Bacon was of the view that people that are half-good and half evil are more dangerous than ones that are completely evil.

Worldly wise people often feel learning is bad because it makes one, (a) not suitable to bear arms, (b) diverts one from the business of politics, that is, people want to debate rather than do, and (c) it makes one slothful. Bacon noted that these views are incorrect because history shows the above are not true for great generals or for great political leaders. In fact, experience without a good foundation in theory makes it difficult to deal with anything that is out of the ordinary. Therefore, learning, particularly of past case studies, always gives more than it takes away and there is no reason why learning should make one slothful, in fact, it is usually the reverse. Bacon was of the view that the learned love learning per se and others only work for money or honour and therefore the learned are more motivated. The result is that learning does not make one slothful; a person's nature makes one slothful. In addition, Bacon noted that learning does not take up too much time because most people just waste their spare time and that learning will not stop one from complying with laws but aid the compliance because it is better to understand laws than to follow them blindly.

Bacon had the interesting view that the fact that the learned are not rich has often helped keep up the civility and honour of life because they do not [cannot] get involved in scandal and dishonesty, and do not want to. As an aside, Bacon notes that a state will prosper only when honour ceases to be paid to wealth. Wealth should be spent on learning and learning should not be used to get wealth. Learned people are often put in charge of youth, which is not a mean employment as some claim, but the opposite because the young need the best people to help them. In addition, learned people do not bring any disgrace to learning other than perhaps by setting too high standards and aims. In fact, in general, Bacon felt that learned people put their country and duty before their own fortunes, which is as it should be, because learning teaches one how insignificant individuals are. Furthermore, learned people are often not interested in individuals because one person is not that interesting and it is not right to try to know someone too intimately but only superficially for decent social intercourse. Learned people often omit social niceties and lesser minds judge them on this basis but one should not judge a person by superficial external criteria. In addition, philosophers must not become toadies, but sometimes have to make allowances for the occasion … but not the person.

The popular belief is that learning can be futile or trivial in three ways, (a) it has no truth or use, that is, it is contentious, (b) learned people can be credulous or curious in a petty or a trivial way, or (c) it can be frivolous, that is, fantastical. Bacon countered this belief by stating that learning must study real nature and not itself or it will produce a complex web of nothing. Learned people should concentrate on the big picture and not get caught up in debating irrelevant trivialities. A real danger to knowledge is the combination of those wanting to deceive and those who are dumb enough to be deceived. In addition, one can become more interested in a turn of phrase than real learning; however, one must be careful not to oversimplify and trivialise learning. An interesting study that investigates this phenomenon in the modern world is that of Sokal and Bricmont (Sokal, 2003). They study aspects of the writing of people such as Jacques Lacan, Luce Irigaray, Jean Baudrillard, Gilles Deleuze, and Felix Guattari among others and show how these authors have often used scientific ideas to mislead and discombobulate.

A number of other minor popular prejudices have been raised against learning and Bacon dealt with them as follows: He recommended that one should not reject traditional methods lightly but one should understand them fully before progressing, that is, “The antiquity of time is the youth of the World” (bk. i). Do not assume everything worth knowing has been found out. New things often seem doubtful beforehand but obvious afterwards, that is, seek new ideas even if they initially seem unlikely to succeed. One should always bear in mind that over time superficial and popular ideas survive rather than deep and profound ones because the superficial ideas are easy to comprehend by the masses. The reduction of knowledge into small specialisations can kill any future major developments and give one tunnel vision, that is, it destroys *philosophia prima*. One cannot make scientific discoveries unless one views one’s speciality from a higher science. Do not seek for truth only in the human mind but rather seek it in nature because it is easy to be influenced by what is well known and familiar and to ignore the unfamiliar leading to false conclusions. Bacon believed that one should not begin in certainties and end in doubts but rather begin in doubt and end in certainty, that is, initially suspend judgement and do thorough groundwork. He also felt that knowledge should be expounded in an ingenuous and faithful and sincere way (humbly) and not magisterially and peremptorily. Furthermore, he believed that many people only interpret or organise knowledge without adding to it. Hence, the main aim of learning is for one to sincerely “give a true account of their gift of reason to the benefit and use of men” (bk. i). However, contemplation and action must be co-joined and united - but not action purely for the making of money.

Bacon noted that knowledge has been almost universally valued in ancient times, for example, in Greek mythology those that improved laws and states were made demigods but those that improved humanity were made gods. Knowledge can help to prevent humanity’s baser instincts coming to the fore, especially when the powerful are also learned. Furthermore, knowledgeable people are better off than ones that have only experience because the knowledgeable can foresee new problems whereas the experienced can only react to new problems. In addition, knowledge makes one patient and of settled mind so that a learned king [leader] is more likely to bring happiness to his people than an ignorant one. For example, because Alexander the Great was learned he was a wise military leader and many other good military leaders were also learned. Bacon concludes this point by remarking that the only thing that great people have is hope and that they have not relied on luck but have made their own luck. In addition, he believed that it is as hard to be a wise person as it is to be a moral one.

Some of the other benefits of learning noted by Bacon are the following: Liberal learning softens and humanises the manners but superficial learning can be counter productive. Learning takes away levity, temerity and insolency. It makes one view both sides of an idea and the difficulties and doubts in a situation. It makes one not accept things that have not been examined and tried, and to accept that all things are mortal or break: the wise person learns to accept and deal with this and accepts that ultimately we are merely specks in the universe. A wise person is one who knows why things happen, and corrects and amends their mind continuously as they use it. Knowledge and learning are the only things that have power over one’s reason, belief, and understanding. Hence, they command one’s will. The truth rightly interpreted approaches divine rule. The gaining of knowledge is the only pleasure that cannot be satiated unlike physical pleasures, that is, knowledge is a good in itself and the products of knowledge outlast physical monuments. However, Bacon concludes this section with the sobering thought that one cannot force others to value knowledge, that is, people will continue to prefer plenty and power over knowledge.

Freud (1939) raised some potentially serious disadvantages to being educated. He developed the view that instinctual control and social adaptation are forced on a child by education, which can then sometimes produce neurotic behaviour. The reason for this is that education is learning to control instincts and it does this by inhibiting, forbidding, and suppressing, which in turn could cause neuroses. Education has to find a balance between total freedom and severe oppression that is different for each child. Hence educators must know psychology and psychoanalysis, that is, they should be psychoanalysed themselves in order to understand the process because Freud was of the opinion that human desire and emotion might be changed by psychoanalysis rather than by moral training.

2.6.1 Idiots and Fools seem to be the Happiest

Erasmus, (1971) at times, expressed a rather jaundiced view of education. He felt that the happier branches of knowledge are those that are most closely related to folly such as medicine, law [these are Erasmus's examples, not mine] and the happiest of people are those who have no traffic with learning and follow nature for their only guide. He believed that humankind is unhappy because it tries to go beyond its natural limitations, particularly in the use of science [and technology?]. His view was, therefore, that the least unhappy are those that come nearest to the instinctive folly of dumb animals and attempt nothing beyond the capacities of humankind. The happiest people are idiots and fools, that is, they do not fear death, are often looked after by society.

As Gregory (1989) mentioned, Herbert Spencer had an even more extreme view than Erasmus did because he believed that a lack of formal education was an advantage although he did revere nature.

2.6.2 The Educated have more to worry About.

Montaigne (1943) noted that in the Christian tradition the devil tempted humanity with the knowledge of good and evil, and that knowledgeable people are often more troubled than the ignorant because their imagination has more fertile ground in which to grow worries. In addition, he added that people are aware of pain and illness (even slight) but not of health and quoted Ecclesiastes by saying that, "In much wisdom is much grief; and he that acquires knowledge acquires travail and torment". Montaigne concluded that humanity's knowledge cannot make it good and agreed with Socrates' realisation that humanity's best knowledge is knowledge of its ignorance and that simplicity is its best wisdom. In particular, one should not parade one's learnedness in front of others.

2.6.3 Culture does not Produce Virtue

Many commentators, such as Honderich (1995), have noted that learning does not necessarily produce cultured civilised people, for example, it is common knowledge that the Nazis during World War II collected many Western cultural treasures and strongly promoted Western culture as the ideal. However, as Shakespeare (1984a) noted, humanity has obtained little from learning and that *true* folly is foolishness in the learned.

Rousseau (1993) took this idea further when he noted that compassion is prior to reason and logical thought; in fact, the civilised educated person often has less compassion than the uneducated. He felt that compassion moderates the love of self and therefore contributes to the survival of the species; in fact, he stated that one should, "Do good to yourself with as little evil as possible to others" (p. 344). He was of the opinion that Socrates's idea of getting virtue via reason is too slow a method and we can rely only on humanity's natural compassion. Rousseau believed that humanity is inherently good and that society turns one into a civilised monster. He felt that a child is not a miniature adult but a creative being that should be allowed to indulge in its sports, pleasures, and instincts. Rousseau's (1911) book

Émile combined nature-worship, child-centeredness, and an emphasis on doing and discovery at the expense of reading and being taught. As Honderich (1995) noted, these ideas had a big influence on Western primary schools. For example, Rousseau influenced people, such as Piaget and Kohlberg, to start investigating child development and saw education, as Plato did, as part of an overall political and social project. Naturalism and Rousseau's (1993) ideas arose in opposition to rationalism and the scientific objectivity of the Enlightenment. The Enlightenment ideas viewed the educated person as rational, reflective, controlled, complex, and objective. Rousseau saw the educated person as romantic, spontaneously intuitive, free, simple, and subjective. According to Rousseau to educate a child protect the child from the corruptions of civilisation, carefully nurture natural spontaneous impulses (which are always healthy), and do not prematurely intellectualise emotion so that intellectual powers can develop without distortion. Feeling should precede thinking with the child controlled by things not the adult will. Nash (2003), discussing Rousseau, noted that education should be concerned with the growth of the unique, ultimately unfathomable child. Gregory (1989) noted Rousseau's view that is, a child must be allowed to grow freely in its own way and in its own time without too much teaching. Therefore, in summary, Rousseau asserted, contrary to the idea of original sin, that human nature was essentially good and societal institutions corrupt man. Children should enjoy childhood. Children must be viewed as children and not as miniature adults. The problems with Rousseau's ideas are the following:

- A distrust of accumulated human knowledge.
- An anti-intellectualism that can lead to the worship of unreason.
- An over reliance on feeling as a basis for human action (Gregory, 1989).

However, many people would probably regard Rousseau's distrust of institutions (schools) as well-justified.

Veblen (1899) highlighted some of the drawbacks of the older forms of education in his wide-ranging study entitled, “The theory of the Leisure Class”. In this study, he showed that the leisure-class tries to maintain traditional standards and methods of culture because they regard these as superior to the modern trends. He felt that the leisure-class regards knowledge of the leisure-class of antiquity as more important than knowledge of commonplace humanity in a modern community. The leisure-class appears to be, prima facia, correct because “canons of taste are race habits, acquired through a more or less protracted habituation to the approval or disapproval of the kind of things upon which a favourable or unfavourable judgement of taste is passed” (chp. 14). This is particularly true of judgements of worth or honour; however, even if the above is true, does it further a more facile adaptation to the economic situation of today? The leisure-class standards of learning are valuable from an aesthetic and not an economic point of view. The leisure-class often argues in a predatory and animistic way because their traditions have come from this background, but this approach is not applicable to today’s world. Educational institutions continue the attitude of the leisure-class and reduce the economic efficiency of the new learned attitude. For example, educational institutions determine what reputable knowledge is and what disreputable knowledge is by, (a) instilling an attitude that merely useful knowledge, that is, non-profitable knowledge, is of lower value than honorific knowledge, and (b) by wasting a student’s time with the study of the classics, dead languages, and obscure terminology. However, he noted that the classics do have a cultural value even if they have no economic value and knowledge of the classics often has only one function, which is to impress others. On the other hand many feel that learning without knowledge of the classics lacks a secure foundation, for example, see Nietzsche’s views above. Hence, learning without knowledge of the classics is often viewed with suspicion. However, now days conspicuous consumption has gained more and more on conspicuous leisure as a means of repute and the classics and dead languages are not so highly valued. Knowledge of the classics was deemed valuable because to acquire this knowledge one needs the time to waste to do so, that is, leisure. It shows one is of the upper or at least wealthy classes and the continued study of the classics in schools is because the leisure-class standards of virtue are archaism and waste. Interestingly in the USA colleges and some UK schools sport is replacing the above function of the classics as an upper-class decoration. Purity of speech and writing are in the same category as knowledge of the classics because good speech has been taken as an indicator of the leisure-class and of spending many generations not in useful employment. Finally, Veblen felt that English spelling was an example of futile classicism and that standard speech is not more precise than a local dialect.

2.6.4 Over-specialisation

Alfred North Whitehead (1925) is one of a number of commentators that have pointed out the perils of over-specialisation. He notes that modern professional training requires people to be able to face novel situations. However, it is making them have a limited range of knowledge. The result is that the remainder of life is treated superficially with the imperfect categories of thought derived from one profession. Other results of this specialisation are, (a) leading intellects lack balance, (b) general co-ordination is done by people who can not succeed as professionals, that is, specialist functions are done well and generalist functions are done superficially and without vision, and (c) progressiveness in detail is matched with feebleness of co-ordination. Whitehead felt that people might know more now days but the speed of technical development has not been matched by a rapid development in wisdom. Wisdom is the fruit of a balanced development and it is the balanced growth of individuality that it should be the aim of education to secure. Traditional education deals too much with intellectual analysis and formularised information and does not develop an appreciation of the full interplay of facts and emergent values. The problem of a balance between general and specialist education and the fitting of education to a democratic society has not been solved. Specialist intellectual training should not have general purely intellectual knowledge added but should involve the students in actually doing something and in relevant analysis. Whitehead believed that education should be structured as follows; (a) the student should concentrate within limited fields (that is, mostly book learning), (b) these studies should not be complicated by other ends, that is, ends not related to the specialisation so that the studies have a clear aim, (c) the other side of training must be in the intuition without excessive analysis, that is, the student must get an appreciation of a variety of values: an aesthetic growth, and (d) an appreciation of the infinite variety of vivid values achieved by an organism in its proper environment is what is needed, not book learning ("We want concrete fact with a high light thrown on what is relevant to its preciousness." That is, art and aesthetic education is required (Whitehead, 1925, chap. xiii)). Aesthetic appreciation increases the depth of individuality and requires activity on the individual's part. Everyone must have an appreciation of the values attached and influenced by concrete facts, for example, a factory has a number of values: social, economic, environmental, et cetera. Hence, modern science and technology must not dehumanise society. The scientific method produces results in a narrow range but this success needs to be tempered with a more general view of the value of scientific results.

2.6.5 Exacerbation of the Insecurities of the Uneducated

Euripides (1946) summed up the ideas of this section when he said that clever knowledgeable people are thought foolish and worthless by fools and are likely to be hated by those who have some learning. However, he also believed that clever people who quietly plot and plan are dangerous. Plato (1875) expressed a similar thought when he stated that people who spend too much time learning and studying philosophy do not know how to deal with real life and real people. Aristotle (1952) made the same point but in a more specific sense by saying that, "Educated men lay down broad general principles; uneducated men argue from common knowledge and draw obvious conclusions" (Aristotle, 1952, p. 608). The commoners therefore charm the crowd's ears more finely and are more effective when addressing popular audiences. Therefore, it may be concluded that, in Aristotle's view, education leads to unpopularity and to wisdom: that is, to both good and bad outcomes.

2.7 Recent Ideas on Educational Aims

Philosophers of education post 1960 such as Phenix (USA), Hirst (UK), and Peters (UK) believed that education should be rationally based and not have Marxist political aims, that is, it should be a pure subject and have no connection with politics (Gregory, 1989). They felt that education should be concerned with the nature of knowledge and the process of passing knowledge from one person to another. In addition, they believed that there were a finite number of forms of knowledge and an educated person should have some acquaintance with each of them. The different forms of knowledge (their language games) must remain separate or confusion will rain. It was difficult to use this theory as a guide to action for educators. Gregory (1989) continues by noting that these theories led to the idea (in a multicultural society) that values must not be taught … rather, how to conduct value arguments should be taught which in turn led to wide spread relativism. Nevertheless, in contrast to thinkers like Phenix et al., Marxism with its overtly political views and its concern with the distribution of education, and the philosophy of education with its insistence on being value-free and its concern with curriculum content dominated education practice until the late seventies. The result of this was children that were ill prepared for work and parents were becoming disenchanted with educators resulting in a school system that needed revamping. However, despite the greater spread of education and the Marxist influence, the school curricula at the higher levels of schooling had not really changed much due to the examination system and the university entrance requirements necessitating a traditional approach. At the lower levels, education for all including the mentally handicapped meant that school curricula aims had to be possible to be achieved in a slow measured way.

Recently modern educational philosophy seems to have moved away from all encompassing educational aims such as education for the greater good, education for universal understanding, education to inculcate the love of learning, or education for power to more narrow sets of educational aims. Two main themes may be identified which run in parallel to each other.

The first theme is that of educational objectives or goals. A typical example of what is being referred to here is the Goals 2000 project in the United States of America. In 1989, the Whitehouse Conference on Education produced the following six goals that were to be achieved by 2000:

- All children will be ready to learn when they start school.
- At least 90 percent of all students will graduate from high school.
- At the end of the fourth, eighth, and twelfth grades, students will demonstrate their competency in such basic subjects as English, mathematics, science, history, and geography. In addition, students will acquire the thinking skills that will allow them to become responsible citizens, independent learners, and productive workers.
- U.S. students will be ranked first in the world in science and mathematics achievement.
- All adults will be sufficiently literate, knowledgeable, and skilled to compete in a global economy and behave as responsible citizens.
- All schools will be free of drugs and violence and will offer an environment conducive to learning.

Ideas such as these do not further our present analysis for two reasons. First, these goals or aims are designed to promote only techno-economic development. Apart from the requirement for responsible citizens, there is no mention of education for the greater good or education for universal understanding or education to inculcate a love of learning or education that may be used intelligently to fill leisure time. In fact, the arts are almost totally ignored. In other words, the above goals lack an overall educational vision or, if they do have one, it is far too narrow. Second, the above goals do not provide useful guidelines for educators who are trying to implement them, that is, there are no standards given by which the goals may be measured other than the rather unhelpful one that the U.S. must become a world leader in mathematics and science.

In the 1950s, an awareness of the vagueness of goals such as those listed above prompted educationalists to look for a better way of describing educational objectives. This search resulted in a taxonomy of educational objectives for the cognitive domain that listed specific educational objectives that students must be able to achieve (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956). This taxonomy was extended to include the affective domain in 1964 and the psychomotor domain in 1972 (Krathwohl, Bloom, & Masia, 1964; Simpson, 1972). However, again these ideas do not contribute much to the current analysis because in this chapter we are attempting to establish the *overall* aims of education so that these overall aims may be focused to obtain the educational aims of an engineering education. Once the aims of an engineering education have been established, the engineering curriculum can be properly analysed.

The second major parallel theme is that of using market forces to determine the system of education and to determine what should be taught. Since circa 1980, there has been a shift in educational policy in most English speaking developed countries, and in New Zealand in particular, to these market driven policies. Without being mentioned specifically by politicians these policies have much in common with the approach recommended by Milton Friedman (1962) in the United States. Friedman recommended that those parts of schooling that had significant *neighbourhood effects* should be subsidised by the state. In other words, where society in general benefits from a part of the educational system then that part of the system should be subsidised by the state. For example, a general level of basic schooling is of benefit to all in a democratic free society and therefore the society should pay for this basic level of education. Friedman extended this concept by recommending that the state payments take place via a voucher scheme in order to create a competitive environment for the institutions and for the educators. The vouchers could only be redeemed for education at *approved* educational institutions. However, at the college and university level (the vocational level) Friedman pointed out that the individuals personally benefit from their education to a far greater extent than society as a whole and therefore the individuals should bear the major costs of their vocational education. He recommended that the state pay for vocational education but once people started working they should be required to pay back the costs of their education via the tax system at a rate which makes the whole system self-financing and reflects the benefit of the education. He recommended that the only type of higher education that should be paid for by the state and not require paying back is any form of education that trains people for citizenship or community leadership or both, that is, a liberal education. This idea of students paying for their vocational education has been partly adopted by the New Zealand government. In

New Zealand the state pays for approximately 69% of the costs of an individual's higher education and the individual has to pay privately for the remainder using student loans or any other means that they can use to raise the money. The philosophical foundation supporting this approach is obviously that individual freedom is to be valued more highly than any overarching purpose for a nation's educational system and as such is not particularly helpful in determining what the purpose is for an engineering education.

2.8 Aims of an Engineering Education

Two sources can be used to obtain the aims of an engineering education. The first are the mission statements of the engineering departments in universities and the second are the specifications for engineering education published by professional engineering societies. This section discusses these two sources.

2.8.1 University Mission Statements

The types of educational institutions that this study is investigating, such as the University of Auckland, The Auckland University of Technology, and The Manukau Institute of Technology, have all signed up to the Washington Accord (2003). The preamble to the Accord states that:

> The Washington Accord was signed in 1989. It is an agreement between the bodies responsible for accrediting professional engineering degree programs in each of the signatory countries. It recognizes the substantial equivalency of programs accredited by those bodies, and recommends that graduates of accredited programs in any of the signatory countries be recognized by the other countries as having met the academic requirements for entry to the practice of engineering. The Washington Accord covers professional engineering undergraduate degrees. *Engineering technology and postgraduate-level programs are not covered by the Accord*.
>
> The signatory countries of the Washington Accord are Australia, Canada, Ireland, Hong Kong, New Zealand, South Africa, United Kingdom, and the United States (Washington Accord, 2003).

This Accord specifies the aims of engineering education which each of member academic institutions must comply with and, in turn, each institution then incorporates these aims in their mission statements for their engineering departments.

According to the Washington Accord (2003), the aim of engineering education is to equip engineering students with the cognitive abilities to do the following:

- Apply mathematics, science and engineering science for the design, operation and improvement of systems, processes and machines;
- Formulate and solve complex engineering problems;
- Understand and resolve the environmental, economic, societal implications of engineering work;
- Communicate effectively;
- Engage in lifelong learning and professional development;
- Act in accordance with the ethical principles of the engineering profession;
- Function in contemporary society.

2.8.2 Professional Society Specifications

The Electrical Engineering profession is promoted by a number of professional bodies the two most important of which each have in excess of 300 000 members: the Institution of Electrical and Electronic Engineers (IEEE) in the United States of America and the Institute of Engineering and Technology (IET) in the United Kingdom. In a similar way to the Washington Accord, these bodies also specify the aims of an engineering education. For example, the IET specifies that an engineer must have the cognitive abilities that enable him or her to do the following:

- Use a combination of general and specialist engineering knowledge and understanding to optimise the application of existing and emerging technology. Maintain and extend a sound theoretical approach in enabling the introduction and exploitation of new and advancing technology and other relevant developments. Engage in the creative and innovative development of engineering technology and continuous improvement systems.

- Apply appropriate theoretical and practical methods to the analysis and solution of engineering problems. Identify potential projects and opportunities. Conduct appropriate research, and undertake design and development of engineering solutions. Implement design solutions and evaluate their effectiveness.

- Provide technical and commercial leadership. Plan for effective project implementation. Plan, budget, and organise; direct and control tasks, people, and resources. Lead teams and develop staff to meet changing technical and managerial needs. Bring about continuous improvement through quality management.

- Demonstrate effective interpersonal skills. Communicate in English with others at all levels. Present and discuss proposals. Demonstrate personal and social skills.

- Demonstrate a personal commitment to professional standards, recognising obligations to society, the profession, and the environment. Comply with relevant codes of conduct. Manage and apply safe systems of work. Undertake engineering activities in a way that contributes to sustainable development. Carry out continuing professional development necessary to maintain and enhance competence in own area of practice (IET, 2005).

2.9 Analysis of General Educational Aims and Engineering Educational Aims

The final section of this chapter will analyse the above general aims of education and the aims of an engineering education in order to determine how an engineering education meshes with a general education. This is a necessary first step towards determining the curriculum for an engineering education because once the status of an engineering education has been established a better understanding will be obtained about what exactly an engineering education is and what should and should not be included in an engineering curriculum.

In part one of this chapter the moral aims of education where covered. In this part it was claimed by many thinkers that the aim of education should be directed at achieving morality and thereby happiness. This meant that for the individual education should build character, provide a person with the correct general fundamental principles to live his or her life by; it should make one able and adaptable. Education should enable one to make correct judgements, be able to correct oneself, and be able to enter into authentic dialog. Finally, education should give one good values, a balanced out look, and wide interests.

If the aims of an engineering education in section 2.8 are studied, it is apparent that only two aims of an engineering education approximate the above moral aims. The first is that engineers should be able to “function in contemporary society” and “demonstrate personal and social skills”. This aim is far too vague to have any real meaning and, in addition, as will be seen when the detailed engineering curricula are discussed in chapter three, there is little in the actual engineering curricula that promotes an engineers ability to function in the wider contemporary society. The second aim that applies to individual morality is that engineers should “act in accordance with the ethical principles of the engineering profession” and “recognise their obligations to society”. This set of ethical principles is a set of principles that apply directly to engineers involved in their engineering activities. They are not a general set of principles that may be applied to one’s wider societal activities and therefore do not play a major role in promoting one’s general moral behaviour. It is therefore apparent that an engineering education is not aimed at and does nothing to develop an individual’s general moral behaviour.

Section 2.2.2 of this chapter looked at moral education from the point of view of the state. In this section the thoughts of a number of thinkers were covered that were of the view that the aim of education should be for the benefit of the state. These thinkers felt that education should enable one to understand what citizenship means and how one can become a good citizen. In this way, education would make one easy to govern but difficult to mislead and, in addition, education should be aimed at producing good leaders. (In fact, as mentioned above, Plato argued that education should be used to segregate people according to their abilities so that they would be of most benefit to the state. This is a view that would not be entertained nowadays; however, Skinner put forward vaguely similar ideas of conditioning and control that, prima facia, are more radical to a 21st Century mind than even those of Plato are.) These thinkers also felt that education should be used to ensure distributive justice within the state and to provide protection to the state by training warriors. The fundamental principal of their views could be summarised by saying that the individual and the state have a symbiotic relationship and each has meaning only through the other.

Again, if section 2.8 is studied it will be apparent that none of the above aims is included in and engineering education. The only engineering aims that approximate the aims in section 2.2.2 are that an engineer should understand the societal implications of engineering work and his or her obligations to society as an engineer; and, in addition, an engineer must be able to function in contemporary society. These aims are far too general to have any practical meaning and only apply to an engineer carrying out his or her engineering work; they do not apply to an engineer becoming a benefit to the state in any general sense.

In section 2.2.3, a number of thinkers put forward the view that the purpose of education was to be of service to god. In fact, many of these thinkers felt that since, in their view, god was the source of all reliable knowledge and truth; educators have no choice but to make the service of god and the contemplation of god the aim of education. In this way, moral excellence will be achieved. Obviously, there is nothing in an engineering education that advocates the service to god as an aim. In fact, it could be argued that an engineering education promotes secular aims.

In section 2.2.4, a thinker such as Nietzsche felt strongly that the purpose of education should be to support the few geniuses in society who understand the society’s culture and to promote the transmission of a society’s cultural heritage. In addition, education should aid one to re-evaluate one’s values and to be aware of the power relations within a state and a society. Again, there is nothing in an engineering education that promotes and transmits a society’s cultural heritage. In fact, because engineering deals with the latest technology, it could be argued that much of what engineering produces weakens a society’s ties with its cultural past by forcing people to devote significant amounts of time learning to use modern technological products that are rapidly superseded. This then forces one to learn to use the latest product thereby repeating the cycle and reducing the time people can spend on their society’s culture.

Section 2.3 moved away from the idea that the purpose of education was to promote the *greater good* and moral awareness to the idea that knowledge qua knowledge was the purpose of education. A liberal education promotes the idea that the purpose of education is to develop effective habits of thinking and knowing; and the idea of knowledge for knowledge’s sake. A number of thinkers under this heading had a religious slant to their ideas in that they saw education as transmitting the knowledge that god reveals to humanity and that one should aim to reveal god in the transitory world around us. Again, there is no part of an engineering education that could fulfil this aim. A fortiori, an engineering education promotes ideas that are contrary to this way of thinking because, as the aims of an engineering education show, engineering promotes a secular scientific view of reality and not reveal truths from god. As section 2.8 shows, an engineering education cannot be regarded as a liberal education because it has vocational aims and does not promote the idea of knowledge for knowledge’s sake. Any habits of thinking and knowing that an engineering education produces are within a narrow range because it is a specialist vocational education.

An important aspect of a liberal education is that it should enable one to develop judgement, wisdom, and foresight. It should enable one to be able to judge the *method* that someone uses to justify a position even if one does not fully understand the topic being justified. In addition, a liberal education should enable one to use reason to counteract desires and to enable one to follow moral strictures such as Kant's categorical imperative. In fact, Kant believed that one of the major roles of philosophy (and presumably education) was to enable people to render a system of morals more complete. Ultimately, reason is to be used to achieve happiness.

The judgement, wisdom, and foresight produced by an engineering education is restricted because, as chapter three on engineering curricula will show, an engineering education is narrowly based on mathematics and science and deals with technology. In other words, there is little in an engineering education to give one a broad view of the world and hence enable one to develop wide-ranging judgement, wisdom, and foresight as advocated by a liberal education. There is even less in an engineering education to enable one to "make a system of morals more complete" and thereby achieve happiness.

Key aspects of a liberal education, as discussed above, are to encourage one to develop a love of learning and to enable one to think in diverse ways. That is, a liberal education is a universal education that prepares one for an unknown rapidly changing future. As one undertakes a liberal education one should grow in one's universality of thought (wisdom) and develop communal ways of thinking. This allows one to "be in all that one does" and be governed by the universal characteristics of a situation and not by personal idiosyncrasies. A liberal education should prevent one from being blindly led by the past and tradition, and should enable one to use pre-suppostionless observation, science, reason, and personal experience to decide a course of action. In addition, a liberal education should allow one to enrich one's experience and develop one's system of morals by having leisure for reading, reflection, and self-contemplation: that is, sufficient leisure time for self-education. Again, as section 2.8 shows and chapter three will confirm, an engineering education is narrowly focused and therefore meets these aims of a liberal education in a limited and circumscribed way. An engineering education cannot be said to develop universality of thought, to develop a diverse way of thinking, or to develop a communal way of thinking. In fact, if the aims of an engineering education are studied, it is apparent that an engineering education is likely to do the opposite and develop in its students a single faceted view of reality. In addition, an engineering education, as chapter three will show, is predominantly science and mathematics based whereas a liberal education values moral development more than purely intellectual or scientific development. As the above thinkers have noted, knowledge and learning should command one's will and not instincts and immediate gratification of desires.

The third major category of educational aims, discussed in section 2.4 above, was that of education for power. Most of the thinkers discussed in section 2.4 had the view that education should be used to ameliorate the effects of power and money rather than be used to obtain power and money. These thinkers believed that paid employment degrades the mind, and that money and power distort the truth. In addition, Marx argued that capitalism is alienating and dehumanising and therefore education should be used to counter these effects by producing a communal man. Finally, thinkers such as Plato (1875) believed that manual skill and vocational training were not even part of a "real" education. Thinkers, such as Whitehead above, further argued that the type of specialisation inherent in a technical education produces an unbalanced development of one's character and that technically educated people are good at the detailed aspects of a society's development but are not good at the overall co-ordination of society's development. The following table summarises the above aims of a general education and compares them with the aims of an engineering education:

General Educational Aims	Aims of an Engineering Education
Moral Education (That is, service to humanity, to the state, to god, or the passing on culture).	Vocational training and an understanding of fundamental mathematics and science.
Liberal Education (That is, universal knowledge and an understanding of the cause of things).	
Education for power.	
Physical training	

Table 2.1 Comparison of Educational Aims

In conclusion, what this analysis has shown is that engineering courses at polytechs and universities cannot be regarded as an education no matter what aim or definition of education one adopts. An engineering "education" is merely a narrowly focused exercise in vocational training. In addition, as the above aims of an engineering education show, an engineering education is not designed to make new scientific discoveries or to develop new areas of mathematics. These functions are the role of pure mathematics and pure science. Ultimately, the role of an engineering course is to train engineers to apply *existing* mathematics and science to the developing and the using of technology in the most cost effective way. It is therefore essential that the above analysis is included in an engineering curriculum. This will enable engineers to become aware of the limitations of their "education" and encourage them to diversify their learning so that their education can fulfil some of the aims that the great western thinkers have set for education.

This analysis has further implications: Because an engineering "education" is so narrowly focused, it does not even vaguely approximate a general education as envisioned by the western thinkers. In addition, the volume of material covered by an engineering education is enormous. Therefore, the curriculum in an engineering course should concentrate entirely on engineering topics and not attempt to cover topics that are more general (such as economics, law, environmental sustainability, et cetera). The reason for this, as confirmed by my own experience as an engineering student and as an engineering educator, is that the time pressures in an engineering course are so great that these non-engineering topics will be so superficially dealt with that they will be almost meaningless. Engineering students will have to wait until they have finished their engineering training in order to obtain a more diverse education and they will have to use their leisure time once qualified as an engineer to obtain a "real" education. In other words, an engineer should view his or her education as a life long project and not as starting and ending during their time at university reading for their undergraduate engineering degree.

Chapter five makes use of the above analysis by showing how engineering education relates to education in general. This in turn enables curriculum designers to concentrate on what is fundamental to engineering education and, as the above paragraph notes, it will help them to avoid being drawn into areas that are not applicable to engineering. In addition, it will enable graduate engineers to obtain a more balanced view of their education and give them a foundation that will enable them to plan their future professional and private development more effectively.

CHAPTER 3
TEACHING AND LEARNING

3.1 Introduction

Chapter three discusses those aspects of learning and teaching that educators should consider in general and, in particular, that they should take into account when devising an engineering curriculum. Ideas of teaching and learning have been debated for millennia and so, for this reason, the chapter begins with a brief summary of the historical theories of teaching and learning. This is necessary because, as will be seen from this summary, many ideas in education recur repeatedly, that is, the ‘education wheel’ has been re-invented many times over the centuries. It is therefore important for educationalists to know the historical development of their subject so as not to waste time repeating work that has already been done. This will enable them to concentrate on developing and advancing the subject while taking into account the ideas from history, that is, they can start from prior knowledge and go forward rather than repeatedly rediscovering existing knowledge.

3.2 History of Teaching and Learning

In order to make the following historical survey concise it has been divided up into four periods: education up to the end of the renaissance, education from the end of the renaissance to the beginning of the twentieth century, the twentieth century, and current trends. These divisions are fairly arbitrary but do cover some of the periods in which educational ideas changed or advanced significantly. In addition, a number of educationalists spanned more than one of the above divisions, such as John Dewey. In these cases the educationalist has been dealt with in the period that most suits his or her ideas.

3.2.1 Education prior to 1600

Rabelais (1990) noted that since the beginning of civilisation nations have valued learning and travelled far to experience it. In classical times, the ideal product of education was regarded to be a person trained in the disciplined study of a limited number of subjects. Prior to 1600 learning was based on imitation and memorizing, and there was heavy emphasis on the intellectual authority of the educator, for example, as in the Socratic method of question and answer (pedagogy, 2006).

3.2.1.1 Plato (429-347 BC)

In modern education prior knowledge is regarded as the starting point for all further learning. Plato (1875) mentions the importance of prior learning in many places. For example, he said that oratory [teaching] is the art of enchanting the 'soul' and therefore to be a good orator [educator] one must know one's audience's 'soul', that is, their prior learning, their experience and what sort of presentation is best suited to each 'soul'. In addition, he warned that a correct education foundation is important because prior knowledge often becomes indelible and unalterable later in life. He confirmed this idea in the Cratylus when he repeated that one must try to get one's first principles on as solid a foundation as possible.

In the Meno Plato produces an interesting slant on prior knowledge when he argues for the idea that all knowledge is already within a person and a educator merely brings this knowledge out; that is, that which we know we do not need to learn and that which we do not know we cannot learn because we do not know what to learn if we do not know it. Plato noted that he was not convinced by his own argument and it is unlikely that the modern teaching profession would accept it in its literal form either. However, it does illustrate a technique whereby an educator may make direct use of a student's prior knowledge to produce further learning and is, therefore, worth consideration from this point of view.

Ultimately what Plato was aiming for in education was for one to have knowledge of 'universals', that is, to be able to pass from the particulars of sense perceptions to one universal concept based on reason. This idea is similar to the idea in modern physics of a 'theory of everything'.

Plato believed that one learns when one is perplexed about something and desires to solve the perplexity. It was largely from this idea that he developed his teaching method. Mill (1963) describes the actual teaching method that he used as follows: initially use logical refutation to examine arguments (elenchus), then test general statements using particular instances, and finally try to define things by starting from the big picture and then narrowing it down by removing what does not apply. Plato believed that there are fundamentally two methods of active teaching, as apposed to inactive teaching, which allows the students to discover knowledge on their own. The first is for an educator to admonish errors: which he notes is not a successful method. The second is for an educator to cross examine the views of the student, that is, the dialectical approach: which he notes is more successful. The dialectical approach is successful because one of the most powerful ways to promote learning is via refutation. If one can refute another's knowledge it forces that person to examine his or her views and for the refuted person to develop intellectual modesty. Closely related to the above but with a slightly different emphasis, Plato believed that knowledge is consolidated and remembered if it is tied to knowing the cause of the knowledge; that is, having the knowledge of a chain of cause and effect enables one to fully internalise, remember and use some aspect of knowledge.

Another concept that is important in modern education is that of experience. Plato realised this when he stated in the Theatetus that 'human nature can not know the mystery of an art [Plato defined 'art' broadly] without experience' (Plato, 1875, p. 147).

Modern education emphasises the idea that an educator should be a guide and role model. That is, someone who guides students through their learning and their construction of knowledge. Plato recognised this role of the educator because he believed that an educator should direct students' inclinations and pleasures to their final aim in life. He felt that one cannot put knowledge *into* another, that is, an educator leads one through the learning process. He saw educators as midwives of knowledge, that is, they do not necessarily have to know the answers to every query, but they do need to know what questions to ask to prevent false knowledge being constructed. Hence educators must aid students to make their own discoveries. However, it is easy to lead students down the wrong path and a good educator will ensure that this does not happen. Plato believed that role models, for example the story of Socrates' death in the Apology, are essential for encouraging the desire and appetite for learning and to motivate students to examine themselves.

Closely linked with the idea of a role model is the importance of an educator's knowledge. Plato confirmed this idea when he noted that to be a good educator one must know one's topic well and one who has had good educators will often, in turn, be a good educator. However, he added that the type of teaching was also relevant, that is, to teach skills, such as various crafts, is easy whereas to teach political wisdom, virtue, or the arts is difficult. Plato highlighted an additional aspect of the idea that educators must be knowledgeable in their subject areas when he noted that students are more likely to learn from someone whom they respect. However, he also believed that educators should ensure that students hear competing points of view to avoid indoctrination. The difficulty with this, as Honderich (1995) mentioned, is to decide which points of view are disputed and who should make this judgement for inexperienced students.

Finally, as Honderich (1995) noted, Plato had some ideas which would not be accepted in the twenty first century. For example, he advocated the teaching of a noble lie to get people to accept their station in life.

3.2.1.2 Aristophanes (450-385 BC)

Aristophanes (1973) wrote about many education ideas which would be considered as modern in his play The Clouds. He discussed or implied the importance of prior learning, thinking for oneself, thinking clearly and logically, working in short intense bursts and then doing something unrelated to the work, and the importance of memory.

3.2.1.3 Aristotle (384-322 BC)

Aristotle (1952) appreciated the importance of prior knowledge and in particular the idea that initial ideas can become strongly held. He wrote that everyone responds better to the familiar and that one tends to stick to (childish) habits of thought. This means that it can be difficult to change incorrect prior learning. Aristotle emphasised the idea of prior knowledge, particularly for instruction by way of *argument*, when he noted that all instruction given or received by way of argument proceeds from pre-existent knowledge and that pre-existent knowledge is of two kinds: knowledge of facts and knowledge of the meaning of terms. We then learn by applying universal knowledge to particular cases. He was of the view that all learning is by means of premises which are known before – whether the learning is by demonstration or by definitions – and learning by induction proceeds in the same way. In addition, he believed that teaching substitutes one quality for another or develops an existing (prior) quality.

Aristotle criticised Plato's ideas in the Meno mentioned above. That is, he did not believe that all knowledge was merely recall. He commented that one may know a universal but only recognise a particular instance of a universal when one comes across the particular instance, that is, all knowledge is not recollection but rather a result of sense perception and memory. Sense perception plants the universal by induction.

Aristotle was of the view that different methods of teaching should be used for different people because different people respond to different types of educational presentations. In addition, he believed that in order to get clear of intellectual difficulties one should discuss the difficulties thoroughly. This is obviously difficult to do in large lecture groups and is probably best done in small groups of 3 or 4 because this will allow the discussion of a number of points of view with out becoming unwieldy as can happen in large groups or becoming limited as can happen with individual tuition. He also noted that different types of knowledge require different teaching techniques. Some may be examined using dialectic and others proceed by showing the nature of something. [Presumably the study of engineering type subjects falls into the second class.]

Aristotle appreciated the importance of experience in education. Palmer, Bresler, & Cooper, (2001) commented that he believed that we learn by experiencing and reflecting on the physical world. Furthermore, a person who has had a great number of experiences is likely to develop good judgement in situations that are new or unusual. However, it is not possible for one to experience everything that is advantageous to a good education and therefore it is necessary for one to have knowledge of universal principles and, in addition, a person who has a knowledge of the 'universals' will make a better educator. Importantly, Aristotle (1952) realised that knowledge takes time to become part of one. This means that, in order to teach a topic, it should be approached in a variety of ways and that the educator should be patient and not expect too much from the students.

Finally, it is essential for educators to be knowledgeable in their subject areas because, as Aristotle noted, 'a man who knows is one who can teach, a man of experience cannot' (Aristotle, 1952, p. 499).

3.2.1.4 Epictetus (55-133)

Epictetus (1990) believed that educators knowledgeable in the field that they are teaching are essential and that learning should change one; if it did not it was not real learning. Therefore, he felt that one should take great care when one sets out to educate others; that is, one should teach only what one truly understands and is suited to. He confirmed these ideas when he wrote that each person who takes up some piece of knowledge must thoroughly 'digest' it before passing it on.

3.2.1.5 St Augustine (354-430)

St Augustine (1961) highlighted an obvious but often overlooked aspect of prior learning. He highlighted the idea that a student's elementary lessons (for example, reading, writing, calculating, logic, the use of rhetoric to set forth the truth, and the knowledge of how to categorise things) are valuable because they are practical skills and can be used to do many of the things necessary for studying other topics.

As far as actual teaching is concerned, St Augustine had many thoughts that were in common with his predecessors. He, like Aristotle and Plato before him and Francis Bacon after him, wrote that one should match the intellectual level of one's material to one's audience and that the material should be graded in difficulty (Augustine, 1961; Bacon, 1990a). In addition, to teach, 'the matter treated of must be made fully known by means of narrative' and to clear up doubtful points 'requires reasoning and the exhibition of proofs' (Augustine, 1961, chap. 27). He also highlighted the danger of using analogies for teaching when he noted that instead of analogies that may ultimately mislead; a good way to teach is by studying examples of how competent qualified people did something. In general a variety of teaching styles should be used to keep the student's attention and the educator whose life is in harmony with his teaching will teach with greater effect.

An important part of St Augustine's theory on education was the idea that an educator should have knowledge of the methods and uses of rhetoric for getting his or her ideas across, that is, for making different types of presentations for different situations. Further, he believed that the best way to obtain knowledge of rhetoric is by reading and listening to eloquent speakers. He confirmed these ideas when he wrote that above all an educator must know what it is that they are professing, that is, have real wisdom. St. Augustine continued by noting that educators reinforce their teaching if they are good role models and set good examples in their field of expertise and as people. That is, if students do not have respect for their educators they will lose respect for what their educators teach.

Finally, St Augustine believed that having motivated students was important. He was of the opinion that the best learning takes place when a student *wants* to learn something, that is, one learns better in a free spirit of curiosity than under fear and compulsion. In fact, one has 'got through' to someone only when that person hears with intelligence, with pleasure, *and* with ready compliance. Again, these are views with which many modern educationalists would probably agree.

3.2.1.6 St Thomas Aquinas (1225-1274)

Thomas Aquinas (1941) also realised the importance of prior knowledge for teaching because he noted that a student learns by moving from universal self-evident principles, that is, prior knowledge, to what is particular.

In order to teach, Aquinas wrote that an educator can proceed in two ways. First, 'by proposing to him [the student] certain 'helps' or means of instruction which his intellect can use for the acquisition of knowledge', that is, by means of simplifying or by means of examples or both. Second, 'by strengthening the intellect of the learner', for example, by proposing the order that principles should be arranged in so that conclusions can be reached (Aquinas, 1941, ques. 117). He believed that an educator aids a student to interpret signs correctly and to organise knowledge. In addition, he had the modern idea that discovery learning was efficacious, that is, he was of the view that one gets knowledge by discovery or by being taught, and that the way of discovery is the best.

Aquinas also believed that subject knowledge is essential and that it enables an educator to teach. After all, even Dante (1970) needed an experienced guide in Virgil to lead him through the Inferno and the Purgatorio. He then needed Beatrice once he got to the higher levels in the Paradiso. Dante's journey however did illustrate that the student needs to have personal experience in order to learn and that he or she needs to get involved in their own learning.

Finally, Aquinas (1941) believed that one naturally understands universal principles and these universal principles can be applied to specific cases in order to learn either on one's own or via an educator.

3.2.1.7 Rabelais (1494-1553)

Rabelais (1990) felt that educators have a large responsibility and that they must take great care with their teaching. He observed that bad teaching can be counter productive and, in addition, much learning is not undertaken because people are more interested in satisfying their immediate bodily and material needs than becoming learned. In fact, Rabelais, like many other thinkers, wondered whether *real* learning existed. This is an idea that will be discussed in more detail below when Wittgenstein's ideas are dealt with.

An aspect of the learning that Rabelais viewed as important was the use of role models. He said that to teach someone first get them to forget their wrong ideas, then put them in the company of learned men and encourage them to memorise the lessons of the masters, and regularly go over what one has learned. He added that one should use the occurrences of everyday life to teach and that learning should not be a chore but that it should be fun. Rabelais's ideas of memorising lessons may not be currently popular but his general ideas are still applicable today.

3.2.1.8 Erasmus (1469-1536)

Most of the above thinkers adopted, to a greater or lesser degree of sophistication, a student centred approach to education. However, Erasmus (1971) was one of the first thinkers to develop student centred education in a truly modern sense. He and the Jesuit Fathers introduced a type of education that had a strong classical foundation but took careful account of the psychological characteristics of the students. They believed that understanding had to precede learning and that the educator's primary task was a careful preparation of the teaching material: the prelection. However, even with this greater awareness of the student’s needs, the concept of mental discipline was still central in the process of instruction. The theory of learning involving mental discipline originated with Aristotle’s idea of ‘faculty psychology’, in which the mind is seen as composed of a number of faculties, each of which is considered to be relatively independent of the other. These ideas came from the theory that mental and spiritual life may be classified in terms of the functions of the soul; that is, knowing, feeling, hungering, reasoning, and doing (pedagogy, 2006).

3.2.1.9 Montaigne (1533-1592)

Montaigne (1943) had definite views on the process of teaching. He was of the view that one learns more from contrast than from example, and from ‘flight’ (that is, what to avoid) than from ‘pursuit’ (that is, what to go after). He felt that discussion with vigorous and orderly minds teaches and ‘exercises’ one at the same time. However, he emphasised that discussion should be vigorous and open because there can be no discussion without contradiction and those who oppose one should arouse one’s attention not one’s anger. Furthermore, he stated that discussions should be orderly because one can not discuss amid chaos and confusion. In addition, he believed that one can never reach the ultimate truth so the aim of discussions should be to make the ‘best run at’ the truth (p. 488). These ideas tie in with many modern ideas of education. Firstly, Montaigne is acknowledging that knowledge is socially mediated, that is, he is foreshadowing the ideas of Habermas discussed below. Secondly, he is highlighting one of the roots of constructivism, that is, that there is no ultimate truth and that each individual has to construct his or her own ‘truth’.

As far as practical teaching is concerned, Montaigne had a version of student centeredness because he stated that the art of teaching is to be able to come down to the student’s level. In addition, he believed that the way to teach is to ask questions involving judgement and then to get the student to give reasons for his or her reply. He also believed that role models were necessary, that is, the educator must not teach only by precepts and words but principally by examples and works of his or her own. Montaigne stated that the possible ways of presenting lessons were by talking, by getting the students to read books, by quoting learned people, and by the educator making summaries of the material. He added that at anytime and anywhere students must be learning ‘so our lessons, occurring as if by chance, not bound to any time or place, and mingling with all our actions, will slip by without being felt’, and ‘away with violence and compulsion’ (p. 123). This again is an idea that modern educators have adopted. That is, the idea that lessons should be integrated with the society and everyday life of the student. Finally, he noted that to teach well one must arouse the student’s appetite and affection for learning so that the student can espouse the learning and not merely know it by rote.

Montaigne also recognised the importance of experience in education. He was of the view that students must internalise and digest knowledge, that is, they must make the knowledge their own so that they can develop judgement in their particular field and the way to make knowledge one’s own is to be ‘put in contact with deeds, and [the educator should] instruct them [the students], not in hearsay but by the test of action’ (p. 128). Finally, he appreciated the importance of a good learning environment and of the educator as a role model because he believed that a good natured educator will be more successful than a martinet. (See Appendix A.2 from an extended quote from Montaigne.)

3.2.2 Education from 1600 to 1900

To the end of the nineteenth century it was taken for granted in the west that the study of Greco-Roman literature and philosophy would have a liberalising effect on the student. Therefore, from the renaissance to the beginning of the twentieth century the ideas mentioned in the above section maintained a firm grip on educators. Nevertheless, a number of thinkers developed or modified the classical approaches to education. These thinkers are discussed in this section (pedagogy, 2006).

3.2.2.1 Francis Bacon

Sir Francis Bacon (1990a) recognised the importance of prior learning and of ensuring that one's fundamental knowledge was as accurate as possible. He noted that without a good foundation in theory one will have difficulty in dealing with anything which is out of the ordinary. This is because knowledgeable people can foresee new problems whereas the experienced can only *react* to new problems. In addition, he stated that pure learning (research) in all fields must not be ignored but should be considered in a similar light to the stomach that digests food for the limbs but does not do anything 'practical' itself.

Bacon believed that one should take great care when using analogies or simplifications in order to teach. He wrote that one must be careful not to oversimplify and trivialise learning because this is likely to give the student incorrect concepts which are then difficult to change. In addition, he believed one should deliver one's knowledge in an ingenuous and faithful way, and admit when one is in doubt. In particular, he was of the view that, superficial learning can be counter-productive.

As far as practical teaching is concerned, Bacon noted that learned men, in the real sense of learned, are often put in charge of young students and that this is not 'mean employment' because the young need the best people to help them … which gives a lie to the contemporary idea that teaching is not a *real* occupation. In addition he felt that knowledge should be presented in such a way as to encourage enquiry and not as a fait accompli. That is, knowledge must be presented in a way that is appropriate to the type of knowledge being dealt with. For example, this implies that engineering courses should not be presented in the same way as courses on literature. Nevertheless, Bacon was still firmly under the influence of classical ideas on education and he emphasised that one must not reject traditional methods of education lightly but understand them fully before progressing. On the other hand, he did comment that new things can seem dubious at first but become obvious in time, that is, one should continually look for new ideas or paradigms as discussed by Kuhn in his 'The Structure of Scientific Revolutions' (Kuhn, 1970). In any field of study it is easy to be influenced by what is well known and familiar and to ignore the unfamiliar leading to false conclusions and slow progress in that field. Therefore, although Bacon believed that using past ‘case studies’ always gives more than it takes away and he also believed that one should always put past knowledge up for re-examination and not except it blindly. In addition, he had the modern view that teaching exercises should closely parallel real life and that equipment that enabled the students to undertake real experiments must be available to them.

Finally, he noted that educators need to know which students to send to other educators who will do them more good; for example, not all students are suited to an engineering degree some would be better suited to an apprenticeship, etc.

3.2.2.2 Thomas Hobbes (1588-1679)

Hobbes (1990) noted that to acquire knowledge one must get one’s fundamentals correct, that is, one’s prior knowledge which fundamentally consists of basic definitions, terminology, and concepts.

3.2.2.3 René Descartes (1596-1650)

Descartes (1969a) understood the importance of prior knowledge when he wrote that to get knowledge one must understand first principles thoroughly and then determine what the results of these principles are.

3.2.2.4 Moliere (1623-1673)

Moliere (1957) believed that students are responsible for their own learning because he noted that persistence and industry are important in success.

3.2.2.5 John Locke (1632-1704)

Many 'modern' educational ideas developed in the time between the renaissance and the end of the 19th century, for example, Locke (1690) wrote that it is not just a student's prior knowledge that is important but also his or her innate abilities. In other words, he raised the idea of nature versus nurture that is still being debated in the 21st century. In addition, he was of the view that educators must engineer for a student to want to learn, that is, as Palmer, Bresler, & Cooper (2001) noted, compulsion in education is inefficient. Locke (1690) was of the view that simple language is better for teaching than flowery language, and that students should dispute to get to the truth but not to win arguments. That is, he believed that education is a socially mediated process. In addition, he emphasised that students should never believe things on the authority of the educator but always examine, question, and doubt everything.

Locke wrote that general [first] principles are not innate in people and must be learnt like all other knowledge contrary to what Plato was trying to show in the Meno. That is, Plato ignored the prior knowledge that the slave boy had such as a system of logic, geometrical knowledge, and the knowledge of numbers, etc.

3.2.2.6 Pascal (1623-1662)

Pascal (1990) believed that educators should encourage students to think for themselves. He stated that to teach one should not show students that they are wrong but rather point out that they have not viewed the matter from all perspectives. In other words, he was noting that there is not one correct way to learn and that students and educators should approach learning topics from as many perspectives as possible.

3.2.2.7 Rousseau (1712-1778)

Rousseau felt that it was the role of the educator to arrange the environment so that the students could learn for themselves. Rote learning and textbooks were an anathema to him. He believed that students learnt best from things they actually experienced, that is, students ‘think very well on everything which bears on their obvious interest’ (Gregory, 1989, p. 686). He, like the Swiss educator, J. H. Pestalozzi, viewed children as an unfolding process, that is, they develop as a product of nature (pedagogy, 2006). However, in their purest form, these naturalistic theories are obviously inadequate in the modern world of technology.

3.2.2.8 Immanuel Kant (1724-1804)

Kant (1990a) was of the view that all knowledge begins with experience, that is, the senses arouse cognition to compare, to connect, and separate leading to understanding. In other words, one must not just ‘sponge up’ what one is told but must create his knowledge using his own reason and fundamental principles.

3.2.2.9 James Boswell (1740-1795)

James Boswell (1990) wrote in his biography of Samuel Johnson that Johnson regarded lectures as a waste of time and that one should rather read the books [and journal articles] that the lectures come from. He remarked that one must read to get a foundation [general principles] and to get a system but these must then be brought to the test of real life, for example, through robust discussion.

However, Boswell noted that Johnson had rather draconian ideas on discipline because he said that it is better to beat children to get them to learn than to make learning a competition with others. The first is quickly finished whereas the second can cause long term problems. He continued by stating, ‘Sir, the government of a schoolmaster is somewhat of the nature of military government; that is to say, it must be arbitrary, it must be exercised by the will of one man, according to particular circumstances' (p. 191). In addition, children, being not reasonable, they can be governed only by fear. An obstinate child must never be able to get away with its obstinacy both for its own good and as an example to others. In addition, the punishment must suit each individual child and educators may beat students but must not permanently maim and can inflict only present pain on them. In contrast, Tolstoy (1998) (and probably most modern educators) felt that students will have difficulty learning from someone of whom they are afraid.

3.2.2.10 Antoine Lavoisier (1743-1794)

Lavoisier (1990) was another thinker who valued first principles and the idea of prior knowledge being important for further study. He stated that to teach a topic its terminology must be defined and its fundamental principles clearly presented.

3.2.2.11 Hegel (1770-1831)

Hegel (1967) defined teaching as the repetition of well established thoughts and learning as the re-thinking the thoughts of others, not just memorising facts and results.

3.2.2.12 Froebel (1782-1852)

Gregory (1989) noted that Froebel was of the view that educators must understand a student's impulse to make things and to be freely and personally active; they must encourage their desire to instruct themselves as they create, observe, and experiment.

Gregory continued by commenting that Froebel had the twentieth century idea that an educator should guide students' self-discovery and not direct them. He believed that an educational institution must at all times maintain a close contact with the family and community, however he under estimated the influence of the society on individual lives.

3.2.2.13 Schopenhauer (1788-1860)

Schopenhauer (1963) had a number of ‘modern’ ideas on education. For example, he believed that in order to learn one must form general conceptions from specific facts and that one should not learn general conceptions first because one will develop incorrect ideas and have to unlearn these misconceptions. In addition, he believed that if students get mistaken ideas early on it becomes difficult to correct them at a later stage. Furthermore, he believed that education should follow the path that the ideas in a particular field followed initially, that is, from the specific to the more general. Educators should find out the natural course of knowledge in their area and use it for teaching. He also believed that it is better to have a few well grounded ideas than many general ungrounded ones and that all learning should come from real life and not from books and theory. Finally, Schopenhauer wrote that a person’s knowledge is mature when there is a perfect match between one’s specific life experience and one’s general ideas.

3.2.2.14 John Stuart Mill (1806-1873)

Mill (1990a) noted that educators must use concrete examples for teaching and not rely entirely on abstract ideas, however, he realised that knowledge does not mean much until experience ‘brings it home’.

In his biography (Mill, 1963) he gave an approach to learning that he found effective. This method involved initially being lectured to by his father and to take summaries of the lectures. He would then rewrite the summaries until they were correct. Once the lecture-summary process was complete he would read the original texts in that subject area and look for logical contradictions and errors. He believed that students should find out for themselves as much as possible and ensure that they understand the knowledge. Their educators should help them only when really necessary and once the students have fully appreciated the problem. Learning should not become just an exercise in memory and educators should always demand slightly more of a student than he or she can deliver. However, this approach does require intelligent, knowledgeable, and sensitive educators as well as students who desire to learn.

Mill (1990a) believed that one must think for oneself but that this requires due study and preparation. Furthermore, all opinions should be fully, frequently, and fearlessly discussed. That is, one should learn the grounds of one’s opinions; however, he felt that this does not really apply to mathematics and science grounds because they do not really admit of much discussion. Importantly, he stated that one should know the opposite opinions to one’s own, as well if not better, than one’s own particularly if one wants to discuss them because it is good to discuss opposing views with people who really believe the opposing view rather than people who just know what it is without really believing it. Doctrines become weakened if they are not continually discussed and grow, that is, both educators and students ‘go to sleep at their posts if there are no enemies about’ (p. 283).

3.2.2.15 Comments on Education to the end of 19th Century

As is clear in the above the importance of concepts such as prior knowledge, learning from experience, discovery learning, the educator as a guide and role model, and a supportive learning environment had been thought about and developed to a greater or lesser degree long before the 20th century. Nevertheless, many of these ideas will be returned to in chapter five which discusses the development of the engineering curriculum.

3.2.3 The early Twentieth Century

Beginning early in the twentieth century a number of general theories were advanced in an attempt to organize the psychology of learning (learning theory, 2006). Some of the important contributing theorists are covered below.

3.2.3.1 Max Weber (1864-1920)

Weber (1945) was one of the first thinkers to highlight a tension that exists in modern universities; that is the tension between research and teaching. He noted that the ability to teach and the ability to do research are not necessarily related. Another problem that he saw with research was that for one to achieve something significant in research one has to follow a narrow specialisation.

3.2.3.2 William James (1842-1910)

William James (1980) was a psychologist who did extensive research into many fields including those related to learning and memory. For example, he summed up the importance of prior learning when he said that 'an educator who wishes to engage the attention of his class must knit his novelties on to things of which they already have perceptions', that is, onto their already formed 'apperceptions masse' (p. 290).

William James noted a difficulty with practical teaching when he wrote that 'an advanced thinker sees the relations of his topics in such masses and so instantaneously that when he comes to explain the topics to younger minds it is often hard to say 'which grows the more perplexed' (p. 692). Therefore for students to follow a topic it needs to be presented in a minute articulate way because they have slow receptions of the topic and do not see it in large masses. In addition, he appreciated that one learns from practical experience.

James also believed that students were responsible for their own learning because he wrote that someone who keeps faithfully busy each hour of the working day will ultimately become competent in their field. In particular, this person will learn judgement in their field.

3.2.3.3 Dewey (1859-1952)

Gregory (1989) noted that John Dewey wrote extensively on education and thinking. In particular he theorised that a student must be provided with experiences out of which his or her thoughts and interpretations would flow, that is, shared experience is a more valuable learning experience than learning from books. In addition, Adler (1990) commented that Dewey felt that learning from experience is necessary because interaction by the students is required and the educator should facilitate this interaction. Adler added that Dewey theorised that the educational experience must be communal and democratic and that the educator should be a leader of group activities and not a ‘boss’. Dewey did not see students as empty vessels passively awaiting knowledge but as active centres of impulse shaped by, but also shaping, their environment. That is, students develop learning habits by interaction with their surroundings and these surroundings should allow and provoke intelligent enquiry. Honderich (1995) summarised Dewey’s educational goal as the growth in one’s powers and capacity for experience with democracy as a guiding ideal. That is, Dewey believed that every experience depends on what has gone before and modifies all future experience, and only when development in a particular direction produces continuing growth does it answer to the criterion of education as growing. Education must provide general and not specific growth. Therefore Dewey (1938) believed that the role of the educator is to see in which direction a student’s experience is moving and guide him or her to further growth experiences. That is, when education is based upon experience and educational experience is seen to be a social process does the education environment change radically from classical schooling.

In *Experience and Education* Dewey (1938) sets out his theory of education as experience. He explains the basic axiom or assumption of his theory of education, discussed above, that there is an intimate link between education and personal experience and lists the aspects of experience based education that are important. In fact, he believed that prior experience is the starting point for all future experience and therefore learning. He states that one learns via experience rather than from books and educators but adds that if one is going to use experience to teach one must start teaching based on a student's prior knowledge and experience, that is a student's actual life experience, and that what good teaching is, is the provision of a continuity of educative experience. That is, new experiences must be related intellectually to those of earlier experiences because existing experiences must not be seen as fixed but be developed and expanded so that they become a means of opening up new *relevant* experiences. In addition, educators must use present life for learning rather than preparing for a remote future, however this does not mean that they can not take a long term view of what they do. Dewey does however warn that not all experiences produce significant education. Some experiences distort or inhibit further experience. Two aspects of experience are important, (a) its immediate agreeableness or disagreeableness, and (b) its effect on future experiences. Therefore real education consists of experiences which live on fruitfully in future experiences. In other words, an important aspect of education by experience is that the experience should have continuity, that is, every experience depends on what has gone before and modifies all future experiences, and only when development in a particular direction produces continuing growth does it produce education as 'growing'. Experience should provide general growth not just specific growth, that is, experience should arouse curiosity, strengthen initiative, and set up desires and purposes that carry a person over 'dead places' in the future. All of the above confirms therefore that the job of an educator is to see in which direction a student's experience is moving and guide this movement. Dewey summed these ideas up by saying that continuity and student interaction will provide an educational experience of significance and value. An educator creates a good environment for educational experiences by understanding the needs and capacities of the students. It is important to realise that when learning takes place it is not just the particular subject that is learnt but also extensive collateral learning takes place. Educators must be able to take a long term view of what they are trying to achieve with their students because teaching and learning are continuous processes of reconstruction of experience. Therefore educators must look ahead and view present experiences as experiences which will influence future experiences. However, he does note that for this process to succeed manners and consideration are important parts of the educational process.

Honderich (1995) noted that in practice, Dewey believed that students should discover all they need to know by working on projects based on everyday life. He was not interested in the classics, history, and the 'inner life'; he was only interested in external practical problem solving. This idea of a practical external type of learning has existed since Plato's time but there have always been many educators who were interested only in the classics and the inner person. Honderich added that Dewey emphasised that a student's interests are vitally important and must not be repressed or humoured, that is, a student's unique bent is important, however, educators must take care not be misled by a student's passing whims. Nash (2003) wrote that Dewey was of the view that subject matter has meaning to a student only if it is related to the student's experience and that it should enable the student to reflect on his or her social experiences and to reconstruct those experiences. In order to do the above Dewey (1938) required educators to remain flexible, spontaneous, and to use unforeseen events but the fundamental material that is taught must be carefully selected and organised and is by no means random. The conditions found in present experience should be used as a source of problems for future experiences and growth by means of exercising the intelligence. An educator must use an 'immature' student's experiences as the starting point to lead him or her gradually through the extraction of facts and laws to experience scientific order. In addition, he recommended that the more mature students also need an appreciation of how means interrelate and not only of the means-ends relationship. (See Appendix A.3 for a summary of Dewey's ideas on thinking).

3.2.3.4 Levi-Strauss (b1908)

Many educators, such as Levi-Strauss (1968), believed that only people with practical experience should teach technical subjects and that for the student significant field work with close contact with acknowledged practitioners was necessary to become a professional. In addition, this field work must be significant and not just consist of a few weeks' of such experience.

3.2.3.5 Piaget (1896-1980) and Herbart

The Encyclopaedia Britannica article on pedagogy (pedagogy, 2006) explains that the German philosopher Johann Herbart made an important contribution to education by providing a mental mechanism that determined which ideas would become conscious and which would be left in the subconscious, to be called upon when circumstances required. This mechanism is termed apperception and is the process by which new concepts became associated with existing concepts to form a matrix of associated ideas called the apperception mass. The new ideas were in this way assimilated to the old ideas. The Britannica continued by noting that the Swiss psychologist, Jean Piaget, argued that such assimilation was not sufficient and that accommodation of the established ideas to the new experiences was also required. Thus Piaget saw knowledge as a series of steps of assimilation and accommodation creating a dialectical constructivism. In each cycle the starting premises are re-examined and active exploration is the basis for learning and understanding. Gregory (1989) noted that Piaget's principle of teaching involves confronting the students with experiences compatible with their 'stage' of development, that is, their forms of thought. However, Gregory believes that Piaget underestimated the importance of social interaction in education.

3.2.3.6 Pavlov (1849-1936) and Conditioning

In Gregory's (1989) article on Pavlov he wrote that the learning produced by an external stimulus was widely studied in the late nineteenth and early twentieth centuries. There are two types of stimulus or conditioned learning, namely, operant or instrumental learning, and classical or Pavlovian learning.

Gregory continued by noting that classical conditioning was the form of learning studied by Ivan Petrovich Pavlov. Some neutral stimulus, such as a bell, is presented just before delivery of some effective stimulus, for example, food placed in the mouth of a dog. A response such as salivation, originally evoked only by the effective stimulus, eventually appears when the initially neutral stimulus is presented. The response is said to have become conditioned. The Encyclopaedia Britannica article on learning theory (learning theory, 2006) notes that classical conditioning seems easiest to establish for involuntary reactions mediated by the autonomic nervous system. Learning new vocabularies, new terms, or new symbols all involve classical conditioning to some degree and it is probable that one trains the emotions in the same way. The Encyclopaedia Britannica article on pedagogy (pedagogy, 2006) adds that people may learn to feel pleasure not only when they meet the original situation causing the pleasure but also when they see some wider context associated with it. Gregory (1989) commented that Pavlov not only studied how conditioning is created but also how conditional reflexes are lost. In short, Pavlov viewed human behaviour as high nervous activity set in train by environmental stimuli (Gregory, 1989).

The Encyclopaedia Britannica article on learning theory (learning theory, 2006) notes that instrumental learning is learning to obtain reward or to avoid punishment. Operant, or instrumental, conditioning is so-called because, in making their response, the students provide the instrument by which a problem is solved. This learning is more important for general education than classical conditioning because educators are concerned ultimately with drawing forth new responses from their students. In instrumental learning learning is active, and, after the early acquisition of vocabulary, terminology, and rules by classical conditioning, the student must use this material in problem-solving responses. However, the Britannica article on pedagogy (Pedagogy, 2006) adds that by using reinforcement, that is, rewards, both sorts of learning can be combined.

In addition, Gregory (1989) writes that both types of conditioning depend not only on the temporal relationships between the conditional stimulus or action and the reinforcers, but also on whether or not the occurrence of the reinforcer is surprising or unexpected. In addition, conditioned behaviour will not associate an action with a reinforcer if another action adequately results in the reinforcer. Furthermore, many examples of non-associative learning, which do not depending on reinforcers, exist. However, conditioning studies can give information about how one intuitively detects and stores information about the causal structure of our environment. It can also give insights about learning that is related to one's purposeful and goal directed behaviour.

The Britannica article on learning theory (learning theory, 2006) notes that E.R. Guthrie found that learning requires only that a response be made in a changing situation. Any response was held to be linked specifically to the situation in which it was learned. In addition he argued that learning is completed in one trial, that the most recent response in a situation is the one that is learned, and that responses (rather than perceptions or psychological states) provide the raw material for the learning process.

Gregory (1989) warns that the significance of conditioned learning however remains contentious**.** More emphasis nowadays is usually placed on cognition and information processing. Human conditioning is less significant than in animals because humans are aware of the signal or action and the link with the reinforcers. In addition, conditioned behaviour is not an automatic reflex, as is usually assumed, but depends on the currently perceived value of the reinforcer, that is, knowledge of the link between the action and the reinforcer is not subconscious but is consciously acquired.

Finally, the Britannica article on pedagogy (pedagogy, 2006) cautions that conditioning theories are not wholly adequate for explaining learning in educational institutions because the student is not simply a responder. Intervening between the stimulus and the response are the students' total consciousnesses which are made up of the results of experience, previous teaching, attitudes, and their own capacity for commenting upon and editing their responses. Simple reinforcement is also inadequate in that the stimulus and the response are not linked in an exclusive one-to-one basis. Several stimuli may evoke a single response, and several responses may be made to a particular stimulus. However, these theories form the behavioural bases for the formation of concepts and the transfer effect from one topic to another. The two basic modes of stimulus-response learning do provide a background analysis of learning, but the complexity of academic achievement calls for extensive elaboration on the simple model. In contrast to the theories of learning via conditioning, cognitive theories of learning assume, in addition, that the complete act of thought follows a fairly common sequence, that is, the arousal of intellectual interest; the preliminary exploration of the problem; the formulation of ideas, explanations, or hypotheses; the selection of appropriate ideas; and the verification of their suitability. Once started, the motivation of cognitive learning depends less on notions of reinforcement and more on standards of intellectual achievement generated by the students. Accordingly, the students may begin to have aspirations and to set themselves future standards that are influenced by their past performances and those of their fellows.

3.2.3.7 Behaviourism

Gregory (1989) writes that a group of researchers closely linked to the ideas of conditioned learning were the behaviourists. They concentrated on overt behaviour rather than the underlying psychological processes that took place when learning occurred. Gregory adds that one of the early behaviourist, Thorndike, showed that behavioural changes were gradual because the 'satisfying state of affairs' that followed the correct response made it progressively stronger or more probable. He noted that patterns of behaviour could be selected by their consequences; however, he found that behaviour could be strengthened only by positive effects and it was not necessarily weakened by negative effects. In addition, Gregory notes that Thorndike believed learning occurs by trial and error, and accidental success. His law of effect states that a response is more likely if it produces a satisfying state of affairs and vice versa. His law of exercise states that learning improves with practice. Therefore, Thorndike (1913) was a forerunner of behaviourism and played down the influence of consciousness in learning. He showed that training on one task was not necessarily transferred to another task.

Gregory continues by noting that Tolman showed that behavioural changes are more complex than pure stimulus-response effects and explored latent learning, that is, the effect of prior knowledge. He showed that the relationship between the environment and behaviour was not simple, where as J.B. Watson emphasised the environmental influences on behaviour to the neglect of inherited differences.

The Britannica article on learning theory (learning theory, 2006) comments that for Tolman the essence of learning was the acquisition by the student of a set of what he called Sign-Gestalt-Expectations. These referred to propositions said to be made by the students that their own specific responses to given signs (or stimuli) would result in a particular set of circumstances later on. Tolman claimed that what the student acquires is a specific knowledge of causality. In summary, his theory was that the student develops expectations based on experience and that learning depends entirely on successions of events. In addition, although less vocal on the point than others, he implied that learning was a gradual process. Therefore Tolman saw learning as a concept and not as a thing so that the activity called learning could be inferred only through behavioural symptoms. The distinction implicit here between behaviour and inferred process is one of Tolman's major contributions and serves to reconcile influential views that might seem completely at odds. The Britannica article continues by noting that classical behaviourism, as developed by Watson, rejected every mentalistic account and sought to limit analysis to such physiological mechanisms as reflexes. Watson argued that these are objective in a way that so-called thoughts, hopes, expectancies, and images cannot be. The opposing view holds that experiential (introspective) activity (exactly what Watson sought to dismiss) does require discussion. Like Watson, Tolman called himself a behaviourist and agreed with Watson's insistence on objectivity. But he also was interested in thinking, expectancy, and consciousness. The Britannica article comments that Tolman found his solution to this problem of incompatible theories through his contact with the Vienna Circle of Logical Positivists, whose deterministic teachings he brought to the attention of American psychologists in about 1920. He maintained that learning is inexorably determined by such directly manipulable variables as the student's previous training and physiological condition and by the response the environment requires. According to Tolman, the development of learning is revealed through the changing probability that given behaviour will result. He theorised that learning itself is not directly observable; it is an intervening variable, one that is inferred as a connecting process between prior variables and consequent behaviour. An attractive possibility is that intervening variables may have discoverable physiological bases. These ideas will be taken up again in the discussion on Wittgenstein below.

The Britannica article adds that psychologists Paul E. Meehl and Kenneth MacCorquodale proposed a distinction between the abstractions advocated by some researchers and the physiological mechanisms sought by others. They recommended using the above mentioned term 'intervening variable' for the abstraction and hypothetical construct for the physiological foundation. For example, Hull (see below) treated habit strength as an intervening variable; defining it as an abstract mathematical function of the number of times a given response is rewarded. The Britannica article notes, by contrast, that Edward L. Thorndike handled learning as a hypothetical construct, but with a physiological mechanism; that is, improved conduction of nerve impulses. Intervening variables and hypothetical constructs need not be incompatible because Thorndike's hypothetical neural process could empirically be found to be the mechanism through which Hull's abstraction operates.

Gregory (1989) writes that Clark L. Hull developed a systematic theory of learning using equations that related drive, habit strength, and reaction potential to responses which he could then use to predict behaviour. This theory offered by Hull over the period between 1929 and his death, was the most detailed and complex of the great theories of learning. The basic concept of his theory was "habit strength"; which he said develops as a function of practice. He theorised that habits were stimulus-response connections based on reward. According to him, responses, rather than expectancies or perceptions, participate in the formation of habits, the process is gradual, and rewards are an essential condition. However, the Britannica (learning theory, 2006) notes that attempts to implement Hull's theories have not been successful.

Gregory (1989) notes that K.J. W. Craik wrote that human thought is to a large degree predictive and that it has objective validity because it is not fundamentally different from external reality and is especially suited to imitating it. He saw the brain as setting up internal models of external reality and then using these models to make predictions. As will be shown below, the modern theory of constructivism does not accept Craik's ideas of objective validity.

The Britannica (learning theory, 2006) concludes its article by cautioning that B.F. Skinner and J. A. McGeoch maintained, in the 1930s and 1940s, that the preoccupation with learning theory was misguided. Their approach was simply to discover the conditions that produce and control learned behaviour. Beyond this, their interests diverged. Skinner studied operant conditioning and McGeoch specialized in human rote memory. Although the study of rote verbal learning had become heavily theoretical by the 1970s, Skinner and his associates, maintaining these empirically based ideas, guided a variety of programs for the practical control of behaviour. Teaching machines and computer-aided instruction, behaviour modification, and planned utopian societies all found their scientific origins in Skinner's rejection of theory in favour of direct efforts to produce required behaviours.

Finally, the Britannica adds that with the growing realization of the complexity of learning, the grand theories of learning and teaching have generally have been abandoned except as historic landmarks. Hope for any comprehensive theory was almost dead in the 1970s. More modest miniature theories remain, many of which are likely to be of temporary value. An account of some of these theories and their major concepts is given in the following sections.

3.2.3.8 Association

The Britannica (learning theory, 2006) writes that a dominant ancient theme in theories of learning has been that of association. Although the concept was accepted by Aristotle, it was brought into the developing psychology of learning by British empiricist philosophers (Locke, Berkeley, Hume, the Mills, and Hartley) during the 17^{th}, 18^{th}, and 19^{th} centuries. Popular acceptability of the notion of association was related to analogous progress in the physical sciences. The physical universe had been shown to consist of a limited number of chemical elements that can combine in innumerable ways. By analogy, a science of "mental chemistry" seemed appealing. The theorized elements in this new "science" were called ideas [similar to the modern concept of memes], said to be based on what were named sensations. The synthesizing principles by which these posited ideas combined in conscious experience were expressed as so-called laws of association. It was suggested that such conditions as temporal and spatial contiguity, repetition, similarity, and vividness favoured the formation of associations, and each was called a law of association. Thus, there were "laws" of repetition, of similarity, and so on.

The Britannica continues that at the end of the 19^{th} century the notion of association was widely accepted among psychologists. German psychologist Wilhelm Wundt took a position nearly identical with that of the British empiricist philosophers. Also in Germany, Hermann Ebbinghaus began to study rote learning (learning theory, 2006). In short, experimental psychology in the Western Hemisphere came to be dominated by what seemed to be a search for laws of association.

The Britannica article notes that the ideas of association psychology have provided some advances over the ideas of conditioning, for example, classical conditioning dependably has been shown to proceed only forward in time. However, in learning verbal associations the situation appears to be quite different since associations proceed in two directions. In addition, the laws of association predicted that the strength or probability of a response should increase with practice even if the elementary associative process occurs in a single trial. Bransford, Brown, & Cocking, (2000) write that one of the fundamental laws of learning is that practice increases learning and there is a corresponding relationship between the amount of experience in a complex environment and the amount of structural change in the brain.

However, the Britannica (learning theory, 2006) cautions that repetition alone does not ensure learning because eventually it produces fatigue and suppresses responses. An additional process called reinforcement has been invoked to account for learning, and heated disputes have centred on its theoretical mechanism. Unfortunately, no single subjective quality imagined by theorists seems invariably effective in providing the reinforcement necessary for learning to take place. It is possible that some combination of introspective influences is critical, or that perceptual processes apply differently from one learning situation to another.

The Britannica continues by commenting that for the above reasons, and many others, not all psychologists have accepted the general validity of the theories of association. Many have suggested that considerations other than association are crucial to learning such as how the learning material is organised. In addition, some theorists endorse the notion of association, but hold it to be less important than is a process of inhibition through which errors in learning are eliminated. Such theorist find support in evidence for the development of learning sets, that is, a student's ability to learn to learn. In addition, it is debated whether all forms of learning represent the same process. This question applies even to relatively primitive phenomena of classical and instrumental conditioning mentioned above. The evidence appears to refute the once-popular theory that involuntary autonomic reactions are subject only to classical conditioning, that is, classical and instrumental conditioning have more in common than was originally realised.

In conclusion the Britannica notes that so far no theory of learning adequately covers more than a small fraction of all the different types of learning phenomena that may be identified, for example, chaining, the acquisition of skills, learning sensory discrimination, the formation of concepts, learning principles, and problem solving. A comparison of various learning theories yields major questions for empirical investigations. Is learning continuous or discontinuous; is it a gradual or a sudden process? Is learning a matter of establishing stimulus-response connections or does it depend on the student's understanding of perceptual relationships? Is reward necessary for learning? In addition, the once-implied sharp distinction between learned and inherited behaviour has tended to become blurred in many recent studies of learning. In short, Bransford, et al. (2000) comment that the views on how effective learning proceeds have shifted, in the second half of the twentieth century, from the benefits of diligent drill and practice to focus on a student's understanding and application of knowledge

3.2.4 Trends in the Second Half of the Twentieth Century

As mentioned above, Gregory (1989) writes that from 1950 to 1980 the emphasis on global theories of learning diminished however the theories of Skinner have been useful for studying the link between conditioning and learning, for example, intermittent reinforcement, punishment, etc. Also, the distinction between classical and instrumental conditioning, as mentioned above, has been challenged. In addition, the biological effects on conditioning have recently been studied, for example, animals are highly influenced by tastes. Some of the approaches that became influential in the late twentieth century are discussed below.

3.2.4.1 Structuralism

The Britannica (pedagogy, 2006) comments that the second half of the 20th century saw a revival of the concept of the structured wholeness of experience, which Gestalt psychologists had first introduced early in the century. The whole of experience, in this view, is more than the sum of its parts. In educational terms, a new experience – such as a new literary text, an experiment in science, or a derivation in geometry – begins by seeming relatively formless and unstructured. The student, who does not yet know his way about the material, begins by seizing upon what appear to him to be important features or figures. He then reformulates the experience in these new terms. The insight gradually becomes more and more structured until finally he reaches an understanding or a solution to the problem. It may be that, in all these processes, the student may try anything he can think of, usually in a haphazard way.

The Britannica continues by noting that Piaget improved upon Gestalt notions by suggesting a thought structure of a more adaptable nature – one that becomes more differentiated and intuitive with experience. He listed three psychological properties of such a structure: wholeness, relationship between parts, and the principle of homeostasis, whereby a mental structure adjusts itself to new experience by assimilation and accommodation. This kind of structuralism found quite independent advocates in other fields. In language, for example, Noam Chomsky believes that there are innate language structures in the young individual, just as Piaget insists that there are innate thought structures.

A belief in the structural nature of experience, as the Britannica notes (pedagogy, 2006), would conceive of the educator as an encourager, example provider, co-analyzer, and co-builder of mental structures that originate in the student in a relatively undifferentiated state. The student is assumed to be active in forming structures and to be making the best he can of the situation he experiences. The educator's task is to help and moderate this process of the student's active construction. This notion works easily and well with able children but entails careful selection with less able students.

The Britannica article continues by noting that others have also stressed the structural nature of advanced cognitive learning. Each area of human knowledge, in this view, is said to have its own unique structure composed of its concepts and their relationships and its own basic modes of progress (ideas closely related to Wittgenstein's concept of a language game discussed below). The article suggests that, from a structuralist perspective, teaching a school subject should not lead to too much tampering with the inherent structural order of the subject but should follow the structure and lines of development of the subject itself. Teaching should not be contrived and artificial. Thus, economics should be taught as an economist views it or physics as a physicist views it or language as a linguist views it: an idea similar to Schopenhauer's mentioned above. Although such ideas are generally attractive, the Britannica notes that they have not been widely translated with any success into actual school practice.

3.2.4.2 Constructivism

The term 'constructivism' has a number of meanings. It can refer to the construction of completely new knowledge such as the development of the theory of relativity by Einstein, or it can refer to individuals constructing their own version of knowledge that already exists such as scientific knowledge, or it can mean knowledge constructed by society such as the development of laws. This section deals with the second form of constructivism; that is, constructivism related to learning existing knowledge.

As noted by Treagust, Duit, and Fraser (1996), constructivism related to learning postulates that learning is a social process of making sense of experience in terms of extant knowledge. This is accomplished best by direct experience of the educator and student in conjunction with opportunities to reflect critically on the experience and emergent problems. Fosnot reinforced this idea when he noted that knowledge involves social debate and suggested that students set the learning agenda (in the broad sense of the term) and that educators set the classroom environment (quoted in Treagust, Duit, and Fraser, 1996).

Treagust, et al. continue by writing that constructivism has two principles; (a) the cognising subject builds knowledge using what he knows and his interpretation of what is taught, and (b) cognition is adaptive and enables the student to construct viable explanations of experiences. Constructs that survive are those that are useful in dealing with multiple contexts. Ultimately all knowledge is personally constructed and socially mediated. Constructivist theory emphasises the importance of fundamental research, that is, the continual testing of concepts.

Constructivist teaching strategies have a number of fundamental steps, as Treagust, et al. note, such as the following: (a) use a constructivist teaching sequence, that is, elicit the student's ideas and only then present new (formal) ideas, so that the educator facilitates the instruction, (b) use a learning cycle approach, that is, explore existing concepts, introduce the new concepts, and then apply the new concepts, (c) use a conceptual change model; that is, create dissatisfaction in the students mind with old concepts, then present intelligible new concepts, and show that the new concepts are plausible and fruitful but do not try to extinguish old concepts, and (d) use a bridging analogies approach, that is, find a path from the student's concepts to more formal concepts by concentrating on the student's concepts that are the most 'correct'.

Tobin & Tippins (1993) write that constructivism takes account of prior knowledge and maximises social interaction in order to facilitate negotiated meaning and provide sensory experiences to build learning, that is, make sense. Educators must monitor students' learning and channel their thinking in productive directions. This requires much interaction by the educators with the students, and in addition it is essential that educators develop ways of assessing what students know.

Von Glasersfeld (1990) comments that constructivism postulates that there is no objective reality that mankind can access and that one constructs one's own knowledge. However, constructed knowledge has to fit socially and physically, that is, it must be an acceptable model. To be a viable theory, Tobin & Tippins (1993) observe that constructivism must have explanatory powers in all or most learning situations. Unfortunately there is little evidence in the literature showing that constructivism has this property.

As will be shown below in the section on Wittgenstein (1958), the word constructivism gives a misleading impression. Knowledge is not constructed with the definiteness of an edifice. It is developed over time in sometimes illogical and random ways. It takes an astute person to realise that their knowledge is not complete and that they need to adjust it to make it more ordered and to 'fit' the facts. Furthermore, it is difficult for an individual to know when they have constructed the 'correct' version of the knowledge that they seek. In addition, it will be pointed out that it is difficult for educators to set up systems for students to construct knowledge because it is not clearly understood how one constructs knowledge for oneself. Therefore it is difficult to know what to do to aid others to construct knowledge, that is, to teach. Finally, it will also be mentioned that it is difficult to assess the knowledge that students have constructed. Many assessments merely assess rote learning, the ability of a student to follow a rule, or the ability of a student to recognise a pattern and to repeat it. It is difficult to assess true understanding; particularly of complex topics.

3.2.4.3 Comments on 20th Century Education

The educational ideas of the 20th century; such as the importance of prior knowledge, the importance of experience, the construction of knowledge, no objective reality on which to base teaching, and the educator as a guide to understanding and knowledge; all turn out to be largely red herrings when investigated using the ideas of Wittgenstein. This probably explains Treagust, Duit, and Fraser's (1996) comment below that mathematics education did not improve in the 20th century. Wittgenstein's ideas will be discussed below.

3.3 Learning

The Encyclopaedia Britannica (learning theory, 2006) notes that education or learning may be defined in many ways. All experiences that affect the growth and development of a student throughout life could be considered as education. In addition, education can be thought of as a continuum between knowing facts and knowing how; that is, knowing how to do and how to increase learning. In its article on pedagogy the Britannica (pedagogy, 2006) comments that the student is more than an enlarging store of information. With the acquisition of learning goes an increasing ability to generalize, abstract, infer, interpret, explain, apply, and create. Cognitive training produces a thinker-observer aware of the types of thought and judgement making up human intellectual activity. Ultimately, the educator aims at a thinker, critic, organizer, and creator.

The pedagogy article continues by stating that each formal educational lesson is a complex of smaller teaching-learning-thinking elements. The progress of a lesson may consist of a cycle of smaller units of shorter duration, each consisting of instruction by the educator and construction by the student – that is, alternating phases in which first the activity of the educator and then that of the student predominates. However, a learning cycle is better seen as a succession of periods of varying length of instruction by the educator and of discovery, construction, and problem solving by the student. The educator selects, arranges, and partially predigests the material to be learned, that is, the educator guides the student's discovery and construction activity. It is a role the educator cannot avoid, and, even in curricula revised to give the students a greater opportunity to discover for themselves, there should be a large degree of selecting and decision making by the educator.

In addition, the pedagogy article points out that educators must face the problem of how to maintain curiosity and interest as the chief motivating forces behind learning. Sustained interest leads the students to set themselves realistic standards of achievement. Self motivation may sometimes be supplemented by extrinsic rewards and standards originating from sources other than the students themselves, such as examinations and outside incentives, but these latter are better regarded as props to support the attention of the students and to augment their interest in the subject matter.

The Britannica (pedagogy, 2006) writes that it is important in any formal educational setting that assessment of some sort is carried out. This post-instructional assessment may, however, have several purposes: (a) to discover when students have reached some minimum level of competence, (b) to produce a measure of individual differences, or (c) to diagnose individual learning-thinking difficulties. A wide variety of assessments can be used for this purpose, including the analysis of work produced in the course of learning, continuous assessments by the educators, essay-type examinations, creative tasks, and objective tests. The content of the assessment material may also vary widely, ranging from that which asks for reproduction of learned material to that which evokes application, generalization, and transfer to new problem situations. However, in the end the attitude and action of the educator remains the strongest factor in successful learning taking place.

In its article on education the Britannica (education, 2006) notes that it is interesting that no limits to human learning have been discovered and that the learning ability of all cultural groups is similar. Also, there do not appear to be limits to the speed at which someone can learn, that is, all can learn fast under the right conditions. Learning, however, is complex with most students learning more than one thing at a time; that is, learning is a complicated matrix of occurrences influenced by the learning environment, for example, in an science lesson a student also learns about his capacities and limits, social relationships, equality, collaboration, competition, and friendship; that is, the student's Weltanschauung. Educators, therefore, need to be aware of the complexity of the learning environment. In addition, educators need to be aware that learning concerns the whole person not just the intellect but includes the body (an unhealthy student will have difficulty learning), the emotions, and the will. Therefore educators should take all of these factors into account. Effective learning usually results when a student is respected, nurtured, strengthened, and stimulated rather than treated as an intellect to be trained.

3.3.1 Factors that Promote good Learning

3.3.1.1 The Learning Environment

The importance of the educational environment for the quality of learning has a long history. Dewey (1938) noted that for educational experiences to be productive it is necessary for both the external environment and the internal conditions within the student to be given equal importance. In addition, Weber (1946) noted that learning in a scientific or engineering environment provides one with physical technology but, more importantly, it gives the student a way of thinking about science and engineering, that is, it helps the student to get a clearer idea of the jargon and zeitgeist of the field.

Bransford, Brown, & Cocking (2000) believe that effective instruction begins with students' cultural practices and beliefs, as well as their academic knowledge. In a constructivist approach to learning, as described above, a student centred learning environment is important because students use their current knowledge to construct new knowledge and what they know and believe affects how they interpret new information. However, sometimes a student's current knowledge tends to support new learning and sometimes it hampers it so educators have to be sensitive to which process is taking place within their students.

Bransford, et al. continue by writing that student-centred environments attempt to help students make connections between their previous knowledge and their current academic tasks. Parents are especially good at helping their children make these connections where as it is more difficult for independent educators. In addition a knowledge-centred perspective on learning environments highlights the importance of thinking about curricula design, that is, to what extent do curricula help students learn with understanding versus promoting the acquisition of disconnected sets of facts and skills? Curricula that are broad but that do not have much depth of content run the risk of developing disconnected rather than connected knowledge. Because many new technologies are interactive, it is now easier to create environments in which students can learn by doing, receive feedback, and continually refine their understanding and build new knowledge.

An important aspect of the learning environment, as Bransford, et al. point out, is the types of assessments used. What are needed are formative assessments which provide students with opportunities to revise and improve the quality of their thinking and understanding, that is, to reflect on their learning. Assessments must correspond with the learning goals that define the particular environment. If the goal is to enhance understanding and applicability of knowledge, it is obviously not sufficient to provide assessments that focus primarily on memory for facts. Endean & Baume (2004) reinforce these general ideas when they state that in order to learn students need feedback on their work and achievements. This feedback may come from various sources such as the course materials, other students, and educators.

3.3.1.2 Student Interest and Motivation

In the 19th century John Mill (1963) noted that an educator should always explain to students why they should learn something in order to motivate them and so that they may understand and appreciate their studies and in the 20th century William James' (1890) research indicated that the more interest students have in advance in a subject the better they will attend. Mortimer Adler (1990) summed up these views when he noted that no learning will take place unless the student is motivated and interested [and has curiosity and a love of learning]. In addition, he believed that learning is facilitated by esteem and docility in the student, and respect for the student's mind by the educator.

The Encyclopaedia Britannica (learning theory, 2006) notes that incentives do seem to invigorate performance up to a point; however, when motivation seems particularly intense, some studies show performance deteriorates. And, indeed, the best-controlled experiments used to determine the effects of different levels of motivation indicate that true learning is the same under different levels of motivation. In these tests the motivation level to learn was varied but the assessment incentives were held the same.

3.3.1.3 Continuity and Connectedness in the Curriculum

The structure of the curriculum will be dealt with in detail in chapter four; however it is worth noting at this point the fundamental aspects of all teaching and learning curricula. For example, William James (1890) believed that to teach students it was necessary to instruct them in such a way as to knit each new thing onto some acquisition already there and if possible to awaken curiosity, that is, new things should come as an answer to a question pre-existing in their minds. Dewey (1938) reinforces this idea when he states that the important aspect of education by experience is that the experience should have continuity and connectedness.

3.3.1.4 Student's Responsibility

Treagust, Duit, and Fraser (1996) state that students are responsible for their own learning. This point seems obvious but in the modern education environment, with its plethora of support services, my personal experience shows that it is easy for students to develop the belief that if they have not succeeded it is because they did not receive the proper support and counselling. That is, they are not responsible for their own failure.

At a more fundamental level, students should develop a love of learning and the correct attitude to learning. The definition of exactly want is meant by the correct attitude to learning has been expounded by many thinkers over time. For example, Epictetus (1990) noted that in order to learn one must 'throw away conceit' because one will not learn if one assumes that one already knows something. In addition, one's will or attitudes underlie all that one does therefore a positive attitude to learning is essential. Furthermore, as Saint Augustine (1961) commented, for one to learn one must keep an open mind, treat all knowledge 'as a matter of doubt', and dedicate one's life to finding the truth. In addition, as Rabelais (1990) noted, students must take responsibility for their own learning by, amongst other things, disputing points to get to the truth but not for eristic reasons or to gain renown.

3.3.2 Psychological Factors Related to Learning

3.3.2.1 Memory

The Encyclopaedia Britannica (memory, 2006) points out that a fundamental aspect of all learning is the ability to remember. Memory is the retention and retrieval in the human mind of past experiences. In fact, the idea that experiences influence subsequent behaviour is evidence of remembering. Therefore learning could not occur without memories.

Many modern ideas of memory have been around for centuries. The obvious fact that one needs memory plus the senses to learn has been recognised since time immemorial, for example, see Aristotle's Metaphysics (Aristotle, 1952). However, an important aspect of memory is that one's experience is derived from memory, that is, our experiences have to be remembered before they can be used in any way. In addition, Aristotle believed that recollection works best if it follows a set of related steps [for example, to remember a formula one should know the derivation]; however a good starting point for these steps is necessary. In more recent times James (1890) noted that the more other facts a fact is associated with in the mind, the better possession of it our memory retains. To form a good memory one should form diverse and multiple associations with every fact required to be retained, that is, one should think about the fact as much as possible and have it fixed in a system. Therefore cramming for an examination is a waste of time because it doesn't give one time to think about a topic. So, for the above reasons, habits of continuous application should be encouraged in educational establishments so that students remember better by thinking more about a topic. However, as Bransford, Brown, & Cocking (2000) point out, memory has come to be understood in the twenty first century as more than simple associations. Knowing how students develop coherent structures of information has been particularly useful in understanding the nature of organized knowledge that underlies effective comprehension and thinking. Rehearsal seems to facilitate transfer of data from short-term to long-term memory. However, the Britannica (learning theory, 2006) notes that once committed to long-term memory, the results of learning tend to endure but can be abruptly abolished when specific parts of the brain are injured or removed; they also are vulnerable to interference from other learning.

In it article on memory, the Britannica (memory, 2006) points out that practice results in a cumulative effect on memory leading to competent performance of skills such as playing music, and reading and understanding. In addition, intelligent behaviour demands memory since remembering is a prerequisite to reasoning and the ability to solve a problem or to recognize that a problem exists. Practice or review tends to build and maintain memory for a task or for any learned material. As mentioned above, information seems to enter long-term storage by these processes of rehearsal and encoding, as if short-term retention is a way station between incoming information and more enduring memory. The Britannica continues that evidence has been accumulating to suggest that a long-term memory is a collection of information or of attributes that can serve in discriminating it from other memories and can function as retrieval cues. Over a period of no practice, however, what has been learned tends to be forgotten. Therefore, the degree of learning is found to be directly associated with the amount of practice. If there were one universal prescription for resisting forgetting, it would be to learn to a high level initially and results seem even better when learning trials are not bunched together. Practice trials may be given in a single session or the same number of trials may be distributed in sessions held on different days. The interrupted schedule is superior to massed practice in that the rate of forgetting that follows distributed practice is slower. Laboratory evidence, as the Britannica notes, confirms the belief that cramming for an examination may produce acceptable performance shortly afterwards, but that such massed study results in poor long-term retention. In addition, information learned in widely distributed practice appears less susceptible to interference; memories established under distributed schedules are also less likely to produce proactive inhibition (see below) than are those learned in massed trials.

Ross (2006) cautions that mere repetition is not sufficient to make memory retrieval effortless and accurate. The success of memory retrieval depends on the proper organisation of the target information within the larger body of knowledge and memories, and not just on repetition. A set of objects, events, or mental representations is organised or structured when consistent relations among the members of the set can be identified and specified, that is, a schema is created. Schemata determine the expectations people have about events encountered and the space-time structure of those events. Gregory (1898) notes that repetition does, however, help to entrench schemata and may help to structure the knowledge because each repetition may trigger new links within the schemata. The types of structure/organisation are the following: (a) categorical or subordinate structure, that is, a hierarchy of categories, (b) co-ordinate structures of a few things (for example, compass points), that is, items don't form a hierarchy but provide a link to each other, and (c) serial or pro-ordinate structure, that is, things are related serially in space or time (for example, the route home from work). Therefore, as the Britannica (learning theory, 2006) writes, in locating an item in memory, one apparently activates a system that has stored a set of related data; then one searches for the item within that system. Considerable evidence supports the above theory that the process of retrieval first locates stored data in some sort of associative network and then selects an item with specific characteristics. The above structures, as Gregory (1989) notes, are embedded in the overall knowledge schemata of everyday life, for example, visiting a restaurant and ordering. Memory systems are not only used to recall information but also for recognition of previous events. Hence, recognition is a two-step process, that is, a judgement of familiarity and then a memory recall similar to that used for information recall. Again, Gregory confirms that the repetition of an event usually aids recognition.

James (1890) summarised the techniques of remembering information by noting that there are three methods that may be used:

- Mechanical methods such as intensification, prolongation, and repetition as described above.

- Judicious methods such as devising a rational system, classifying, analysing, etc. In modern terminology this process is called chunking. Gregory (1989) points out that more items can be remembered when they are coded or chunked, for example, more numbers are remembered when they are in recognised sequences. However, as the Britannica (memory, 2006) notes, these encoding mechanisms may adapt or relate fresh data to information already present to the point that what is coded may not be a direct representation of incoming stimuli.
- Ingenious methods, such as associating facts with an easily remembered framework, is James's third technique. The Britannica (memory, 2006) confirms that this principle of encoding new information to previously stored data tends to aid memory function. The Britannica continues by stating that when encoding techniques are formally applied, they are called mnemonic systems. Mnemonics are aimed at helping one to learn and remember specific bits of information by organising information in ways that one can more easily comprehend and remember, for example, the loci method links places with images and a word. Mnemonics are useful for memorising lists of words or dates, etc., but are not much use in daily life. Mnemonics have various problems, for example, the problems with the loci method are the following: (a) the words memorised must be translatable into images, (b) the words must be presented slowly for memorisation, and (c) one must be able to isolate each word presented and not confuse the images. However, mnemonics do show that imagery is a powerful means of learning and remembering. They also show that intellectual skills can be displayed in different ways that aid learning. Gregory (1989) cautions the best way to learn information is to understand it. In short, mnemonics do have their uses but they are limited.

Gregory (1989) writes that at a neurological level the physical basis of memory (the engram) is not known and further it is not known whether the physical brain change that is supposed to take place when something is remembered is everywhere or nowhere. Physical context plays a role in memory retrieval, that is, the same physical context improves recall. Mood also plays a role in recall, that is, people who are happy while learning should be happy during recall for the best results and similar comments apply to one who is sad while learning. He notes that we do not recall an event in its original form or even an attenuated version of it. We reconstruct it - by drawing upon the cognitive structures into which the perceived components of the event were organised. Thus what is reconstructed during recall shows not only omissions and abbreviations but also elaborations and distortions. Gregory points out that when we recall an event we are not recalling the event but our previous recall of it. He adds that memory errors are of two kinds: (a) errors of retrieval, for example, remembering events that didn't happen because they fit some cognitive schemata, and (b) errors of judgement of familiarity.

The Britannica (memory, 2006) notes that an important aspect of memories and remembering is the phenomena of forgetting. In general, it is found that associations tend to interfere with or to inhibit one another. A pre-eminent theory of forgetting at the behavioural level is anchored in this phenomenon of interference; that is, in retroactive and proactive inhibition. In retroactive inhibition, new learning interferes with retention of old memories; in proactive inhibition, old memories interfere with the retention of new ones. These two forms of inhibition are accepted as the major processes in forgetting, proactive inhibition usually being assigned greater importance. Both phenomena have great generality in studies of any kind of learning, although most research among humans has been with verbal learning. The Britannica article cautions that sources of interference, however, are pervasive and should not be considered narrowly. For example, any memory seems to be established in specific surroundings or context, and subsequent efforts to remember tend to be less effective when the circumstances differ from the original. Although interference has attracted wide support as an account for forgetting, it must be placed in perspective. A number of deductions from interference theory have not been well supported by experiment.

The Britannica continues by stating that it is interesting to note that when the degree of learning is experimentally controlled, different kinds of information are forgotten at about the same rate. Nonsense syllables are not forgotten more rapidly than are ordinary words. In general, factors that seem to produce wide differences in the rate of learning show little effect on the rate of forgetting. However, despite discrepant evidence, mnemonic systems may prove an exception to this rule. This powerfully indicates that ordinary estimates of one's rate of forgetting are often spurious, being obscured by uncontrolled differences in learning ability. The degree of learning does seem to be almost completely irrelevant to the rate at which one forgets.

Finally the Britannica comments that it seems likely that dramatic instances of sudden forgetting, as in amnesia, can be seen to be adaptive. In this sense, the ability to forget can be interpreted to have survived through a process of natural selection in animals; for example, when one's memory of an emotionally painful experience leads to severe anxiety, forgetting may produce relief. However, an evolutionary interpretation makes it difficult to understand how the common gradual process of forgetting survived natural selection.

3.3.2.2 Transference

Gregory (1989) notes that in learning the transfer of concepts may be positive or negative, for example, Latin may positively transfer to help learning French but negatively transfer to hinder the learning of German. Perceptual abilities and skills can transfer from one part of the body to the other, that is, something learnt in the right hand can help the left hand to learn that skill. Training may be transferred from one task to another. However, the Britannica (pedagogy, 2006) cautions that although much empirical research has been done on the transfer of learning, it has produced mixed results. Some researchers have found that transfer has been possible only insofar as there have been identical elements, and even those who claim a transfer of methods generally insist that transfer has little chance of success unless it is actively explained and applied to the new learning. Students have to apply methods consciously to the new field in order to succeed. The opposing view would be that each subject is unique and requires its own mode of thought. An intermediate view, however, is more likely, that is, there is both a common and a specific element in each intellectual field, that mental discipline or transfer of training is to some degree possible but only insofar as the similarities and analogies are utilized, that the process is deliberate, and that a residue of specific subject matter remains in each field. This specific subject matter then requires specific learning.

3.3.2.3 Symbols and Language

Since much learning takes place via symbols, this section presents some of the advantages and disadvantages of symbols and some of their dangers, particularly when then are used for teaching and learning.

Aristotle (1952) wrote that bad reasoning is often due to the terms used in the reasoning being ambiguous or loosely defined and Plato (1875) said that educators must use names carefully and well because they are ‘instruments’. However, as Rabelais (1990) commented, one can discuss the pros and cons of a topic and appeal to the emotions - but to really learn about difficult topics, signs are required. This idea was confirmed by Levi-Strauss (1968) when he said that for the clear expression of diverse concepts and to maintain objectivity symbols, such as are used in mathematics, are necessary because languages are not objective enough. Lavoisier (1990) added that an accurate terminology is essential to understanding and communicating the ideas and facts in any science.

Pierce (quoted in Sierpinska, 1994) wrote extensively on signs and symbols. He believed that cognition is a system of contents or signs and not of subjective mental experiences. In general a sign is a combination of an icon (resemblance), a symbol (imputed quality), and an index (contingency). Pierce was convinced that the characteristic that gives life and meaning to a sign is its use. Therefore educators must take care in the use of symbols when teaching.

Symbols allow, (a) abstraction and high-level analysis of ideas, (b) rapid thought, and (c) the linking of ideas and the forming of short cuts. As Sierpinska (1994) concisely noted, symbols are often an affordance for understanding something. The disadvantage of symbols, as the Britannica (education, 2006) points out, is that one may think only abstractly and not apply ideas. In addition, in teaching and learning educators may confuse symbol manipulation with education.

3.3.2.4 Nature vs. Nurture

The idea that each person has unique inborn characteristics has been around for millennia; for example, Aristotle (1952) noted in the Nicomachean Ethics that a private individual education is superior because each person has different strengths and weaknesses and therefore needs individual tuition.

According to Gregory (1989), an area in which the debate about nature versus nurture has been particularly prominent is in the discussion of IQ. Gregory points out that no one is certain what intelligence is or what IQ tests measure. Broadly, intelligence is the capacity to learn from experience and the ability to adapt to one's environment. Many 'factorial' theories of intelligence have been developed which try to relate intelligence to human abilities (factors) and possibly a common factor 'g'. Gregory continues by noting that another way of defining intelligence is to try to link it to how people solve problems, that is, solving a problem depends on meta-components, performance components, acquisition components, retention components, and transfer components of intelligence. These two approaches, that is, the factorial and problem solving methods may be linked because meta-components and 'g' appear to be the same thing. Gregory believes that meta-component functioning is probably under-emphasised in most forms of intelligence test because they don't measure social skills, motivation, persistence, the ability to set goals, etc. However, neither of the above two approaches makes it clear how much of intelligence is due to heredity and how much is due to the environment/training.

3.3.2.5 Thinking Skills

The idea that thinking is a skill and a skill that can be developed has a long history. For example, Mill (1990c) noted that one should make students aware of their ignorance and aware that being knowledgeable is beneficial; that is, students should be taught how to compare, contrast, and evaluate modes of action using logic. Lavoisier (1990) noted that many factors lead one to make false judgements and to make suppositions rather than drawing real conclusions such as imagination, self-love, and self-confidence. He added that historical authority also gives incorrect ideas the appearance of truth. However, to overcome these false judgements and suppositions he suggested that one should restrain and simplify one's reasoning as much as possible, stick to the facts, and test ideas via empirical methods.

James (1890) wrote that we learn to discriminate between things if they have many small differences or many disparate associations, or if in the past there has been a big difference between two things we will be able to discriminate if the difference is now smaller but of the same type. James continued by stating that the greater part of human knowingness is the ability to make a mass of simple inferences, that is, 'if A then B' and that much thinking consists of trains of images of concrete things. He noted that humans are educable because they can take a given mode of thought and break it up into elements and recombine them anew. He added that humans inherit few settled instincts but use reason instead and people who are the most instinctive at the outset are those which are the least educated in the end.

According to Gregory (1989), the mind can be seen as consisting of hypotheses of perception and of understanding, that is, hypotheses about perceptual data may be ambiguous, distorted, paradoxical, or fictional, and perhaps never close to the truth. Nevertheless, the private hypotheses of perception and the shared hypotheses of conceptions make up our reality. Perception is related to conception by perceptually guided activities requiring understanding such as making or mending things. Hence people see more fully when they understand what they are handling and looking at: a fact that may be used in education. Gregory continues by pointing out that practical operating skills such as deciding, judging, prioritising, and breadth of vision are not the same as knowledge absorbing skills such as perceiving relationships, attention skills, ordering information, and memorising. However, Gregory notes that many types of thinking skills are not productive. The skills that are not efficient are the following: (a) point-to-point thinking, for example, if a then b and if b then c, etc,

(b) a highly intelligent person who defends a point of view without exploring it, that is, a good debater, and (c) thinking using the tools of logic but using the wrong initial perceptions. For good thinking attention needs to be directed, for example, to look for pluses, minuses, and interesting points of view in a situation.

In Gregory's view, an important aspect of thinking is imagination. All normal people can imagine things. Some people say they learn better from reading and others from hearing; however, these different preferences are not constitutional but rather a function of the learning strategy used and the situation. However, Gregory points out that images as objects of mind are not well understood although simple tests can determine if a person is imagining something or looking at a real object. He adds that eidetic imagery is little understood.

Most educational systems claim to value independent thinking; however, independent thinkers are rare since most people tend to be conventional in thought and action. On the other hand many independent thinkers, such as van Gogh (2003), feel that 'orthodoxy' is persecuting them. Gregory (1989) notes that independent thinkers generally have only one particular theme. Most independent thinkers believe they have an important message and try to spread it from altruistic motives. Gregory writes that closely related to independent thinking is lateral thinking. Lateral thinking is about provocations that help us generate hypotheses, for example, random words. Lateral thought is used to change perceptions and concepts, that is, modify the input to the brain. For lateral thought one needs to break from judgements that reinforce existing patterns of mind. One must look for new ways of generating hypotheses from conventional facts and perceptions. Gregory points out that lateral thinking usually gives only a starting point for a new idea that then has to be developed. However, as Kuhn (1970) notes, it is often difficult for new ideas to take hold because old paradigms do not yield in the face of a few counter examples. People often deny facts, logic, and contradict themselves rather than shift their frame of reference.

Ross (2006) notes that one of the most important influences on contemporary learning theory has been the basic research on expert students. He continues by stating that expertise of any kind involves more than a set of general problem-solving skills; it also requires well-organized knowledge of concepts and inquiry procedures. Bransford, Brown, & Cocking (2000) comment that learning theory can now account for how students acquire skills to search a problem space and then use these general strategies in many problem-solving situations. However, there is a clear distinction between learned problem-solving skills in novice students and the specialized expertise of individuals who have proficiency in particular subjects. These activities include such strategies as predicting outcomes, planning ahead, apportioning one's time, explaining to one's self in order to improve understanding, noting failures to comprehend, and activating background knowledge. They continue by stating that it is not simply general abilities, such as memory or intelligence, nor the use of general strategies that differentiate experts from novices. Instead, experts have acquired extensive knowledge that affects what they notice and how they organize, represent, and interpret information in their environments. This, in turn, affects their abilities to remember, reason, and solve problems (Bransford, Brown, Cocking, 2000; Ross, 2006). Ross (2006) notes that experts have acquired a great deal of content knowledge that is organized, and their organization of information reflects a deep understanding of the subject matter. An experts' knowledge cannot be reduced to sets of isolated facts or propositions but, instead, reflects how the knowledge is applied.

Sierpinska (1994) adds that a student's skills and knowledge must be extended beyond the narrow contexts in which they were initially learned. For example, knowing how to solve a math problem in a particular environment may not transfer to solving math problems in other contexts. It is essential for a student to develop a sense of when what has been learned can be used, that is, the conditions in which it may be applied. Failure to transfer knowledge is often due to students' lack of this type of conditional knowledge. She continues by writing that learning must be guided by generalized principles in order to be widely applicable. Knowledge learned at the level of rote memory rarely transfers; transfer most likely occurs when the student knows and understands underlying principles that can be applied to problems in new contexts. That is, students are helped in their independent learning attempts if they have conceptual knowledge. In addition, she notes that it is useful to study students' concept formation because this shows the role of their mental representations of problems, including how one problem is similar and different from others and how they understand the components in the overall structure of a problem.

Bransford, Brown, & Cocking (2000) point out that students are most successful if they are mindful of themselves as learners and thinkers, that is, skills of metacognition provide strategic competencies for learning. Therefore, students' self-awareness as learners and well developed assessment strategies assist in keeping learning on target and encourage the students to question their understanding. They continue by stating that students can become independent learners if they are capable of sustaining their own learning, in other words, they are able to become life-long learners, or as Sierpinska (1994) noted, no one is ever fully educated and therefore one must learn how to learn.

However, Bransford, et al., comment that due to limited experience and undeveloped systems for logical thinking, many students' knowledge contains misconceptions. Therefore a student's curiosity and persistence must be supported by educators who direct the students' attention, structure experiences, support learning attempts, and regulate the complexity and difficulty levels of information. (See Appendix A.3 for a summary of Dewey's ideas on thinking).

3.3.3 Understanding

3.3.3.1 The Nature of Understanding

Probably the most important and difficult concept in learning is that of understanding. At its most fundamental, education involves students developing or constructing a degree of understanding in a particular field and then applying this understanding in a creative way. This primacy of understanding has been understood by most writers in the field of education as the following short historical summary shows.

Plato (1875) stated that virtue is obtained by having ‘right opinions’ rather than definite knowledge, that is, one can have true opinions without knowledge and that it is difficult to teach ‘right opinions’. One way in which this comment may be interpreted is to view opinions as socially mediated and therefore if one has opinions that are accepted in one’s culture and society then they are ‘true and right’. In other words, a large proportion of human understanding is a social process. However, this approach can be problematic, for example, Plato noted that rhetoric, which was popular in ancient Greece, is the art of persuading by instilling belief without knowledge and therefore rhetoricians are more persuasive to the ignorant than the knowledgeable and hence may distort a society’s beliefs and opinions. Plato discussed understanding in many places, for example, in the Phaedrus he said that unless the written word is discussed and debated, that is, a dialectical approach is adopted, and the outcomes of this process carved on one’s ‘soul’ the knowledge would be valueless. Knowledge has no value just because it is written by a respected person. According to Plato individuals must take possession of knowledge in their own way, that is, in modern terminology, students construct their own knowledge or as Rabelais (1990) said, one must meditate on one’s lessons. Plato (1875) emphasised the idea of the social mediation of knowledge when he stated that education directs one to the ‘right reason’ which the laws and the eldest and the best in society agree are truly right. In other words, what Plato is saying, is that knowledge and understanding are social processes and can not be carried out on one’s own. Plato’s axiom that if one really knows something one does not have to write it down because it is part of one’s soul could be used as a measure of one’s understanding of some topic. However, Plato was puzzled about just how one knows and understands something. Descartes (1969a) noted that to solve a problem one must first understand it and Montaigne (1943) stated that most learning is inflated pedantry or the parroting of other peoples’ knowledge and he asked what the use of learning is if understanding is absent. Montaigne further noted that understanding is more important than raw learning because being an able person is more important than being a learned person. More recently, Dewey (1938) agreed with Plato when he noted that all human experience [which presumably includes understanding] is ultimately social in that it involves contact and communication.

This foreshadows Habermas's (1972) concept of communicative action. However, in the educational field it is difficult to be sure that a student has constructed knowledge that corresponds with the community's accepted knowledge. This problem, as Sierpinska (1994) noted, may not be as pronounced in the mathematical and scientific fields because mathematical and scientific objects are creations of the human mind but are embedded in a system of logical necessities and consequences that relate to other mathematical and scientific objects.

It is commonly accepted that one's own conceptions and understandings influence how we interpret other peoples' understanding, that is, there are no objective truths about other people's cognitive constructs. Therefore an iterative process is necessary to understand a student's understanding, for example, one must develop a theory or model of a student's understanding and then test this model. One should use different points of view to interpret a student's response to assessments of his or her understanding. A theory of a student's understanding is helpful but one must also look at the data without referring to a theory so as not to be prejudiced. In order to investigate a student's understanding teaching experiments, which are exploratory tools used to understand what might go on in a student's head, may be adopted. These experiments may include activities such as the following: (a) observe the student in 'natural' nonstressful settings in order to get some idea of their understanding, (b) use interviews to discover a student's concepts and ideas and then use these concepts and ideas to plan and implement teaching, (c) check a student's conceptual relationships using, for example, conceptual maps as discussed below, (d) use diagnostic test items, and (e) computerised diagnoses. Because it is hard to assess a student's understanding conceptual maps may be used as an assessment tool. However, a student's knowledge structure is complex so it is difficult to know how good a conceptual map is or how valid they are. According to Treagust, Duit, and Fraser (1996) little is known about the process of how a student understands something, but understanding seems to be fostered by informed purposeful activity and when students have control over their personal learning approach. However, they comment that no set strategies can guarantee to improve classroom practice. That is, they believe that teaching concepts requires negotiation, group work, discussion and 'wait time'. Solomon (1992) observed student discussions on scientific topics and found that the students did not know what knowledge sources they were using to construct knowledge during the discussions. However, it does seem clear that social interaction does play a large role in knowledge construction and that social knowledge and formal knowledge complement each other. Airasian and Walsh (1997) point out that one of the problems with the popular concept of constructivism is that it is difficult to implement because theory and practice are different, that is, students do not construct meanings as educators expect. In addition, constructivism is time consuming and difficult to assess or evaluate. Furthermore, as Case (2004) points out, it is possible that what a student regards as understanding in a certain field of study may not be the same as what the educator regards as understanding in the same field Finally, Sierpinska (1994) comments that it is difficult to conceive of an objectively good or correct understanding of something, for example, how would one practically check that a student's understanding does not contradict any statement of a particular scientific or mathematical theory? There may be an infinite number of statements that could be made about any particular theory. It is much simpler to prove that a student's understanding is not perfect because, for this, only one contradiction is required.

However, as discussed above, not is it only difficult to understand what degree of understanding a student has constructed in a particular field but the fundamental concept of understanding is difficult to comprehend. The infinitive verb 'to understand' is ambiguous and has many meanings as the Oxford English Dictionary illustrates with its twelve A4 pages of definitions (Simpson & Weiner, 2006). As an example, Sierpinska (1994) writes that in mathematics one may understand the structure of a class of problems or one may understand the class of problems by recognising the structure in them. She continues that a conceptual understanding could mean knowing the definition of the concept, how it may be interpreted in different situations, and how it links to other concepts, that is, the concept is already made and existing; or something could be understood on the basis of the concept, that is, the concept is synthesized in the process of understanding the 'something'. Hence, one can understand multiplication or understand something based on multiplication, that is, there is a distinction between what is to be understood and on what basis something is to be understood. She notes that there is a difference, therefore, between an object of understanding and an object used for understanding, that is, recognising the structure that an object of understanding falls into. In addition, understanding can be viewed as a construction of the meaning of something, or, conversely, the meaning of something can be viewed as a certain way of understanding it.

Understanding, as Sierpinska (1994) notes, often involves comprehending certain characteristics of an object of understanding, that is, a fuzzy sub-set of characteristics without fully understanding the object. She continues that understanding can be an exploration why something is as it is based on premises, reasons, causes, etc.; or something can be viewed as being understood if an action using the understanding produces an expected result; or understanding can be knowing how to perform an action; or it can be recognising the main components of something and the relation between them; or understanding could be feeling and thinking like the author of a text feels and thinks; or it could be a reader constructing his or her own meaning of a text. For example, one may understand a thunderstorm by understanding its cause via the laws of physics; or by being able to predict the storms normal course, effects and the states of the atmosphere before and after the storm without knowing its cause.

Sierpinska points out that for an act of understanding to be less ambiguous one must know what is being understood; on what basis is it being understood, for example, such as via reason or via empathy, etc; and the operations of the mind that are involved in the act of understanding. In addition, one needs to understand the environment that the concept to be understood is embedded in; that is, understanding is usually contextual rather than merely formal inferences from general and abstract statements. However, she states that a further complication with the concept of understanding is the fact that meaning and understanding are intertwined concepts and, as with understanding, meaning is hard to define probably due to its self-referential nature, that is, a definition of meaning has to have meaning. She adds that generally one may view understanding as being in one’s mind whereas meaning is in the public domain. The meaning of a text, for example, does not change but its significance can change over time and in different situations, for example, one approach views art as having significance but not having meaning.

It is clear therefore that there are many views of understanding. Piaget (1978) viewed understanding as being based on conceptualisations that allow one to explain why a certain action has been successful and to imply why certain possible actions would be or would not be successful. His theory of equilibration (Piaget, 1975) regards something as understood when one has a feeling of order and harmony in one's thoughts. Maslow (1966) felt that the reductionist view of understanding which emphasises simplification and integration does not give a full account of human understanding even in science which has many concepts which are just experimental and can not be reduced to more fundamental forms; such as the constancy of the speed of light. For example, a mothers understanding of her baby is hard to analyse using reductionist techniques or as Werner Heisenberg (1969) stated, he could have a theory in his head but not in his heart. Positivist thinkers, in Sierpinskas (1994) view, disagree with this approach and she states that they believe that one must observe the facts, state the regularities of co-existence and succession of phenomena, and based on these regularities one must make one's predictions and base one's technology; all else is worthless and even senseless. Korzybski (1950), however, showed that the whole situation is further complicated when he noted that whenever one says something *is*, it is *not* because whatever one says is formulated in words and what one means to say is usually not words [I hope the reader understood these words]. Many mathematicians and scientists, on the other hand, regard something as understood if one can build an accurate mathematical model of it, for example, Greeno, quoted in Sierpinska (1994), notes that knowing, understanding, and reasoning are grounded in mental models rather than in representations stored in the mind. In other words, understanding is based on the ability to do something. However, he continues that mental models of reality can become confused with reality and, in addition, one can predict future events correctly using a total misunderstanding of the underlying phenomena, for example, using Ptolemy's astronomy for astronomical predictions. Conversely, 'suchness' understanding, as Sierpinska points out, takes the opposite view that sometimes one just understands something because it is as it is and one does not *do* anything with this type of understanding, for example, understanding a picture, a poem, or a piece of music.

Understanding may be difficult due intrinsic reasons as described above or due to extrinsic reasons. As Richard Feynman (1965) wrote:

> What do we mean by "understanding" something? We can imagine that this complicated array of moving things which constitutes "the world" is something like a great chess game being played by the gods, and we are observers of the game. We do not know what the rules of the game are; all we are allowed to do is to *watch* the playing. Of course if we watch long enough, we may eventually catch on to a few of the rules. *The rules of the game* are what we mean by *fundamental physics*. Even if we knew every rule, however, we might not be able to understand why a particular move is made in the game, merely because it is too complicated and our minds are limited (p. 2.1).

Ultimately, in Sierpinska's (1994) view, our understanding of whether we have or have not reached the essence of a matter upon which we have reflected is a personal decision based on feelings, that is, Piaget's harmony of thought discussed above.

Sierpinska continues that it seems clear, however, that understanding has at least four mental operations: (a) identification, discovery, or recognition of the object to be understood, (b) discrimination of the object; that is, recognising that it is different from other objects, (c) generalisation, and (d) synthesis. The above may be regarded as a local synthesis in mathematics or science, or it could be regarded as global syntheses such as those which have paved the way to the unifications that mathematics has experienced over the last two centuries. These syntheses used such basic global organising ideas as functions and graphs. In education a difficulty arises because the synthesis has to be made by the understanding subject and not by the educator. Understanding is, in her view, an active process (see Wittgenstein's conflicting views below) and our minds are not passively imprinted with ideas of things from the outside. The understanding subject, the student, is the agent whose relation to the object of understanding is mediated by his or her own activity. As a result of the action of the student on the object, a new object of understanding may come into being, that is, the student has produced or constructed something. In this view of understanding attention focuses on the transformation and the production of objects as a result of activity. This approach is close to that of Piaget's (1978) for whom understanding is built in a complex dialectic process between action and reflection upon the action. He found that development starts with an action on objects; it then goes through making connections between objects, and ends with a perception of and reflection on a whole structure. None of these stages can be skipped if a conceptual understanding is to develop. Short cuts are possible in teaching but not in learning. Piaget's ideas indicate that educators should not be overly concerned, initially, with meaning and understanding, and never actually let the students instrumentally use methods and techniques for the solution of meaningful problems. That is, it is not possible to understand theory before becoming aware of the usefulness of its tools. However, as Sierpinska (1994) noted, educators must be careful not to fall into the trap of allowing their students to merely reproduce techniques and methods by rote with out understanding … a mid-path is required.

Sierpinska continued that in addition to the above four mental processes the necessary but not sufficient conditions for understanding something are; (a) something to be understood needs to be brought to one's attention, however, if one is not familiar with a particular topic one will not know what to attend to, (b) one needs to be puzzled about it, that is, to have a question brought to one's mind, and (c) the process needs to take place in a social environment of some form. She believes that the first step of attention may be applied on a meta-level. In other words, attention may be applied to meta-consciousness, that is, to attend to how we are going about solving a problem. However, as Poincaré (1952) pointed out, in education it is difficult for the educator to communicate what should be attended to. There have been many cases of sudden illuminations or unexpected acts of understanding something that one was not thinking of at the moment, that is, some form of processing has been taking place unconsciously. These sudden acts seem to contradict the idea that for understanding something needs to be brought to ones attention. (See Appendix A.1 for an extended quote on education from Poincaré.) However, most people who have had these experiences have been assiduously attending to the 'problem' for an extended time prior to the sudden event. Weber

(1946) reinforced this idea when he noted that ideas occur to one when they please and not when one wants them to, but a prerequisite is long thinking around the subject and a passionate devotion to it.

Sierpinska (1994) believes that improving understanding in mathematics and science education can be approached in three ways. One approach concentrates on developing teaching materials that would help students to understand better, another concentrates on diagnosing or assessing the students' understanding, and a third attempts to build models of understanding in the students. Sierpinska, on the other hand, does not believe any of these methods are truly successful and has developed the idea of 'obstacles' leading to understanding. She argues that acts of understanding that overcome an obstacle, whether developmental or epistemological, are the most important for developing understanding. These obstacles are subjective and varied, for example, they may be due to the difference between scientific thinking and language, and everyday thinking and language. However, it is difficult for an educator to know what obstacles a particular student is trying to overcome and an added complication is that once the obstacle has been overcome previously developed ways of understanding may have to be modified by the student making the whole process complex. She states that it is necessary, however, for an educator to provide challenging questions and problems to students so that a gate to conceptual thinking is opened to them. That is, the educator must lead the student's thinking beyond the forms of thinking that he or she is using and force it into forms of thought that are more elaborate. This in turn will sow the seeds of further epistemological obstacles to be over come and, it is postulated by Sierpinska, a deeper understanding will develop.

In addition to all the above comments, Sierpinska adds that understanding is both developmentally and culturally bound, that is, instruction and knowledge are cultural as well as social affairs. Or, as Cackowski (quoted in Sierpinska, 1994) succinctly noted in this context, "every really significant idea is born as a heresy and dies as a prejudice". However, as discussed in chapter one, in order to limit the scope of this thesis, it will concentrate on western education so these cultural aspects will not be investigated.

In the twentieth century the person that has done more to influence the above discussion than anyone else is Ludwig Wittgenstein (1958). He noted that it is not simple to understand how statements get meaning which implies that large parts of education are puzzling. He was interested in and investigated what is meant by, and what the differences are, between knowing, understanding, and just blindly following a rule. He showed that understanding is *not* a mental process like feeling an increasing pain because one suddenly understands something without a 'process' taking place. For example, what actually is the process of reading? When one sees a word that one knows one immediately understands it, there is no *process* of understanding that takes place.

Wittgenstein developed, amongst many other things, the concepts of a language game, of private languages, and of understanding not being a mental process. Many of these concepts have been extensively discussed in the literature and have been misunderstood or trivialised by many authors. Anthony Kenny (1973) has analysed some of these misconceptions and has provided an insightful summary of Wittgenstein's thought. It is essential, as he points out, that Wittgenstein's original works are read and understood rather than relying on the secondary literature which can be misleading and in many cases is incorrect or over simplified. These comments apply, particularly, to Wittgenstein's concept of a private language but also to his works in general.

Wittgenstein's ideas are fundamental to education. For example, the concept of a language game, put simply, means that for a student to fully understand a field of study, say electrical engineering, the student must understand the environment, in the broadest sense, that the field of study inhabits. That is, the student must understand the jargon, the symbols, the slang, the abbreviations and short cuts, etc used by professional engineers. It is this total environment that Wittgenstein was referring to when he referred to a particular activity having a particular language game. A student who does not understand the language game of engineering will have great difficulty in communicating with other engineers and really understanding engineering concepts. Therefore one of the fundamental parts of an engineering education will be the students developing a comprehension of the language game of engineering. This idea will be returned to in chapter four.

The second of Wittgenstein's concepts, that of a private language, has implications for western philosophy and for western education. Wittgenstein showed that a totally private language is not possible. In other words, solipsism is not possible and even Descartes' *cogito ergo sum* on which much of western philosophy is based does not make sense. As far as education is concerned, this concept means that radical constructivism is not possible, which in turn means that some form of objective reality must exist. We may not have an accurate model of this reality but it must nevertheless be there. The implications of the impossibility of private languages for teaching and learning are extensive. First, it means that students can only construct meaning by interacting with the physical world, including remote authors, and with society. They can not construct real meaning *entirely* on their own. Second, it means that curricula must be structured so that students have a range and a variety of options for constructing understanding because no one approach will provide the full range of interactions that a student needs in order to develop a deep insight into a particular topic. This point will be further expanded in chapter four.

The third of Wittgenstein's concepts, that of understanding not being a process but a mental event also has extensive implications for teaching and learning. If understanding is not a process but a sudden event then it is difficult to structure teaching so that these events will take place because it is almost impossible for a third party (an educator) to know precisely what learning activity will trigger understanding in a particular individual (student). This is true because there is no understanding of how this event comes about or even what it is exactly. There are many documented cases of people having eureka moments (see Poincaré and Weber above) but there does not appear to be any explanation in the literature of what exactly these events are, what causes them, or how they can be reliably produced. In other words, educators have no guaranteed way of ensuring that students will understand a particular topic.

A few paragraphs above it was mentioned that Sierpinska noted that understanding in mathematics and science can be improved in three ways: using appropriate teaching materials, using diagnostic techniques, or building models of students' understanding. However, if the occurrence of understanding is not a process then it is difficult to know what type of teaching materials to use and the diagnostic techniques will at best show that understanding has occurred but will not explain why it occurred or what exactly caused it to occur. As mentioned above a diagnostic technique that is often used to determine whether a student has understood a topic is to get the students to undertake some activity that requires the understanding. However, even this approach can be misleading. For example, students may be able to do a wide range of complex-number calculations without understanding what $\sqrt{-1}$ actually is. Another diagnostic technique that is often used in engineering is to require the students to build a model (mathematically or physically) and then use this model to make predictions. It is then hypothesised that if the predictions are correct the model is correct and the students have understood the topic. However, as the example of Ptolemy showed, this hypothesis is incorrect.

To date no one seems to have been able to develop a model of how a student's understanding occurs. This lack of model is probably because models model processes which are distributed in time whereas understanding is a sudden event that is not distributed in time. In addition, understanding often comes about in, what appears to be, non-logical, random, and mysterious ways. Furthermore, it is difficult for the individual to know when he or she has understood something, that is, how can one be certain of one's own understanding let alone try to model someone else's understanding.

Another conclusion that can be drawn from the above is that the modern educational emphasis placed on a student's prior knowledge as a starting point for further learning is idealistic. This is because it is difficult to comprehensively assess a students understanding of any complex topic because, as Sierpinska pointed out above, any complex topic would require an infinite number of questions to be asked of the students in order to determine whether they completely understood the topic. Therefore, at best, an educator can have only an approximate understanding of a student's prior knowledge and understanding, and therefore only an approximate idea of where to start with any further learning. This problem is further exacerbated in large classes and with diverse groups of students. In addition, an educator has no reliable way of determining just how approximate his or her knowledge is of a particular student's prior knowledge and understanding.

It is therefore clear that much of the modern educational theory seems to be logically cogent but is practically difficult or impossible to implement. In summary the modern approach is for the educator to start from prior knowledge and understanding, provide a stimulating educational environment, provide students with educational experiences that build on their prior knowledge and understanding in order to extend their learning, and integrate assessments into the learning in order to provide feed back to the students and the educators. However, because understanding is not a process, it is not known what triggers it in a particular individual, and it is difficult to assess; particularly if the topic is complex. Therefore, most of the steps in the modern approach to education are difficult or impossible to implement with any degree of certainty that the educator has adopted the correct approach for a particular student or group of students. This probably explains Treagust, et al.'s comment, mentioned below, that mathematics education has not improved during the 20th century. Finally, it is interesting to note that the above explains why rote knowledge and rule following is so much easier to 'teach' and assess than understanding.

The conclusion that the above leads one to is that educators must create a large and diverse range of learning situations for students to interact with and hope that something triggers understanding. In addition they must provide a large and diverse range of assessments in order to get some (vague?) idea whether the students have understood a topic or not … this may be thought of as the shotgun approach to education. Again, these aspects of teaching and learning will be expanded on in chapter four on curriculum design.

3.3.3.2 Understanding for Creative Use

As mentioned above, teaching consists, fundamentally, of two things: creating understanding in students and then getting them to use this understanding creatively. As the Encyclopaedia Britannica (creativity, 2006) notes, creativity may be viewed as the ability to construct or otherwise bring into existence something new, whether it is an innovative solution to a problem, an innovative method or device, or a new artistic object or form. This section discusses the creative use of knowledge.

Gregory (1989) points out that creativity deals with many fairly separate ideas which means that it is hard to define. He adds that in schools the drive for creative students caused teaching to move away from rote learning and set syllabuses, and emphasised the student's 'own discovery'. According to Gregory current research into creativity has taken two forms: (a) the study of the lives of creative people, and (b) studies into the process of thinking and creating. This research has found little correlation between highly original adults and their school or university results or with their I.Q. In fact, he notes that most highly renowned USA scientists were B+ students.

Gregory continues that the human brain seems to work the most productively and creatively by having periods of intense concentrated work followed by periods of complete relaxation in which no thought is given to the work. In addition, in order to innovate one must break the grip on ones imagination so that one's powers of logical-seeming story telling impose themselves, that is, one must subvert conventional wisdom or to use Einstein's well known quote, one must 'gain access to one's dreams'. However, he notes that psychologists, neurobiologists, etc do not know how the human abilities of logical thinking and free association combine to produce a creative work of real value.

The Britannica (creativity, 2006) points out that psychological experiments in the areas of motivation and learning have shown that novelty is a spur to creative action. There appears to be a tension in humankind between the establishment and maintenance of a constant environment, and the interruption of this constant environment in the interest of novel experiences. These psychological studies of creative people have observed this tension in such characteristics as intuition and intellect, the conscious and the unconscious, mental health and mental disease, the conventional and the unconventional, and simplicity and complexity.

The Britannica continues that creative people are usually intelligent in the ordinary sense of the term and can tackle life's problems as rationally as anyone, but often they refuse to let the intellect rule; they rely strongly on intuition and they respect the irrational in themselves and others. The Britannica notes that above a certain level, intelligence seems to have little correlation with creativity, that is, highly intelligent people may not be particularly creative. This is probably because a distinction should be made between convergent thinking, that is, the analytic reasoning measured by IQ tests, and divergent thinking consisting of a richness of ideas and originality of thinking. The Britannica article comments that both types of thinking seem to be necessary for creativity, although in different degrees depending on the task. For example, a mathematician may exhibit more convergent thinking and an artist more divergent thinking.

This article points out that a number of phases have been identified as being typical of creative thinking. The first phase would be preparation in which the creators assemble and explore their resources and make preliminary decisions about the resources' value for solving a particular problem. The second phase is incubation in which the creators mull over possibilities and move about from one possibility to another free of rigid rational or logical preconceptions and constraints. Incubation seems to be partly unconscious as it proceeds without the individual's full awareness. The third phase is illumination which occurs when the resources fall into place, and a definite decision is reached about the solution. The final phase is verification or refinement. This is the process of making minor modifications and committing ideas to a final form. The article continues that often objective standards for judging creative activity (for example, poetry writing or painting) are lacking and so an important criterion for the assessment of creativity becomes the emotional satisfaction of the creator. Although the above four phases have been ordered in a logical sequence, the Britannica notes that they often take place in different ways from one creator to the next. In addition, many creative people attain their creative aims by special strategies that are not easily describable or even fully comprehended by the creator. As mentioned above, it is important to note that the key phase, that of illumination, is not well understood and, as mentioned, often proceeds unconsciously. That is, it is similar to the mental event of understanding in that it does not appear to be a process but is a sudden occurrence that cannot be controlled and probably cannot be taught.

The Britannica cautions that the phases of preparation, incubation, illumination, and verification are characteristic of creative thinkers generally but do not guarantee that a worthwhile product will be produced. This article also notes that creative outcomes also depend on whether the creator has the necessary personality characteristics and abilities. In addition, the quality of creative thinking seems to be closely correlated with the training of the creator. The artist who produces oil paintings needs to learn the basic painting techniques and technologies; the scientist who creates a new theory does so using his or her background of previous learning. Furthermore, creativity intimately blends objective and subjective processes, that is, successful creators learn how to release and to express their feelings and insights.

Finally the Britannica states that it is clear therefore that creative thinking involves using intrinsic resources to produce results and that this process seems to be influenced by the early experience and training of the individual. It adds that educational situations that promote unorthodox thinking seem to foster the development of creativity but do not guarantee it.

The conclusions that can be drawn from the above are the following. A part of the creative process seems to take place subconsciously and we are all aware of the phenomena of solutions to problems ‘coming to us’ when we are not thinking about the particular problem. These solutions seem to be an event similar to the event, described above, that Wittgenstein has identified for understanding. In addition, there does not appear to be any method of teaching or guaranteeing that creativity will take place. As mentioned above, environments that encourage creativity seem to help and, in addition, as noted by Poincaré and Weber in section 3.3.3.1, it is necessary for creators to assiduously attend to a problem for an extended time before there is any possibility of a sudden creative event taking place. Weber (1946) reinforced this idea when he noted that ideas occur to one when they please and not when one wants them to, but a prerequisite is long thinking around the subject and a passionate devotion to it. All this then means that it appears unlikely that creativity can be taught in a way that guarantees that the student in question will become creative. Therefore the two fundamentals of teaching: creating understanding in a student and getting a student to use his or her understanding creatively are both difficult to do and that no guaranteed way of doing either exists. Developing understanding and creativity in students can be supported and encouraged by teaching but can not be guaranteed.

The next section discusses some of the aspects of teaching that may support understanding and creativity.

3.3.3.3 Serendipitous Reflection

Closely related to the concept of understanding is Cowan's (2004) idea of serendipitous reflection. As has been mentioned above it is important that educators encourage students to become reflective learners. However, as Cowan points out, reflection on one's studies not only enables one to understand a particular topic but occasionally produces ideas that enable one to extend one's understanding beyond a particular topic or to produce productive ideas that are not directly related to the topic. By definition, serendipitous reflection is not something one can purposefully set out to generate but serendipitous reflection begins when, for no reason that we can identify at the time, we suddenly perceive, question, spot another option, or have an insight. Nevertheless, one welcomes it when it occurs, and hopes that habits of questioning and reflecting developed in the other forms of facilitated reflection will carry over to good effect in producing the occasional serendipitous reflection.

Rogers (Rogers, 1967, 1983) maintains that the following three conditions in the learning environment may increase the probability of serendipitous reflection occurring, and in turn support the construction of understanding and the development of abilities from experiences:

- empathy, that is, intellectual or emotional identification with the student,
- congruence, that is, there is a close matching or congruence between what is being experienced at the gut level, what is presented in the awareness, and what is expressed between the educator and the student, and
- unconditional positive regard, that is, the wholehearted acceptance that a student's questions, however difficult to locate relative to the immediate learning task, are genuinely of importance to that student.

3.4 Teaching

Historically, as the Encyclopaedia Britannica (education, 2006) points out, educators have differed on how knowledge should be communicated. The traditional method, particularly during the time of the renaissance, was via an *apprenticeship* and trial and error: for example, children learning role identity such as how to become a father. The second method is for an educator to *tell* the pupils something and then the pupils memorise it and the educator then assesses what the students have retained. The third method is via *dialog* in which there is more equality between the participants than in the above two methods. The Britannica continues that educators have also differed on whether instructional groups should be grouped according to ability or made diverse. Uniform groups are more efficient to teach but heterogeneous groups produce better tolerance of others and better understanding of others. In addition, educators have differed on their conceptions of control and discipline. Depending on one's view of humankind, that is, whether humans are untrustworthy or not determines whether they need more or less discipline/control. Ultimately the aim is to teach self-discipline but the difficulty is to know whether it is better taught via control or via freedom. Another historical tension in teaching that the Britannica mentions is the idea of competition. It is not clear whether children naturally compete or whether society teaches them to compete but compete they do. Should education encourage or discourage competition? Should a school prepare students for a competitive society or should it try to remodel society by discouraging competition among the young? Most modern schools tend to send mixed messages about competition. Finally, according to Honderich (1995), much modern education confuses relativism with tolerance.

Honderich also points out that the aims of teaching may be viewed in many ways. At the practical level, educators aim to teach what the results of inquiry are and how to get more of them and how to distinguish them from competing results/ideas. Getting students to accept points of view often involves techniques which do not use only rational argument, for example, humour, the educator's character, educator reputation/authority, etc all play a role in teaching. This supports Plato's idea that teaching is possible only from soul to soul, that is, in small groups.

A sobering statement made by Treagust, et al. (1996), in chapter ten of their book, however, is that the teaching of mathematics and science has not improved much over the last century. Treagust, et al., continue by noting that modern teaching is based on a students' prior conceptions because students' prior knowledge can have a powerful influence on their learning and for teaching to be regarded as successful it must bring about a long-term change in these concepts. Finally they state that it is unfortunate, but it is still not well understood by educationalists, how a student's beliefs and initial concepts interact with new concepts and information. The reasons for these unencouraging outcomes for education have been discussed above. However, there are still many approaches to teaching that support learning, understanding, and creativity.

3.4.1 Prior Learning

3.4.1.1 Importance of Prior Learning

Treagust, et al. (1996), state that one must teach from what the student knows and has experienced and that the theory of constructivism explains why a student's pre-instructional concepts are significant to all future learning. This is because all future learning or knowledge construction takes place from a foundation of the student's prior knowledge. They note that pre-instructional knowledge is difficult to change because it guides and determines new knowledge acquisition. It therefore follows that a student's prior concepts should guide the development of the curriculum and the teaching methods used. They state that one may obtain and insight to a student's prior conceptions by means of diagnostic tests and the look, listen, and discuss method, and then use this information to devise teaching approaches. However, as has been discussed above this process is difficult in practice and this probably explains why mathematics education has not improved much during the 20th century.

Treagust, et al. continue by noting that ultimately educators seek to develop techniques for determining prior knowledge because teaching is fundamentally the process of raising the status of 'correct' concepts and lowering the status of 'less correct' concepts. In addition students must be taught to think *about* their concepts and not only *with* their concepts if any form of conceptual change is to happen. As discussed below a technique of change is the use of cognitive conflict to build on existing ideas. They comment that in mathematics and science the multiple visual representations of data are important for learning to take place, that is, educators should use a multi-representational approach to teaching which includes existing student knowledge together with contextual problems and experiments.

3.4.1.2 Student Interest and Motivation

As has been mentioned above, in a number of places, the interest and motivation of students is important in the educational process. Therefore some understanding of human motivation is necessary for teaching. The Encyclopaedia Britannica (education, 2006) points out that human motivation is more variable than that of animals and is not driven by instinct. Humankind is therefore more flexible and can be creative and can build on the work of its predecessors. The Britannica continues that education in the past often treated students as animals with a form of education resembling training. Modern education, however, should emphasise initiative, creativity, choice, decision-making, and freedom. It adds that historically schooling has been successful at teaching mechanical, repetitive skills but not at developing the intellect and will. In order to do this motivated, interested students are required.

3.4.2 Types and Methods of Teaching

This section deals with the different ways in which teaching may be undertaken, however, many of the techniques and methods of teaching have already been discussed in the above sections; particularly in the historical summary at the beginning of this chapter. This section will therefore concentrate on types and methods not already covered or on techniques not historically used by educators.

3.4.2.1 Use of Analogies

Educators have to be careful when using analogies for teaching because, as Treagust, et al. (1996) have noted, a student's pre-instructional ideas can be strongly held. In addition, they comment that paradigmatic examples are not necessarily a good way of teaching because there is no sure way of transmitting the example from the educator's mind to the student's mind. The student must construct or reconstruct examples so that they become paradigmatic for the student in a more objective way. The educator can assist the student by organising situations against which the consecutive tentative forms of the examples can be tested and in which change can be discussed and negotiated. Examples are, in Sierpinska's (1994) view, an indispensable prop and an obstacle to understanding depending how they are handled.

3.4.2.2 Teaching Machines

Gregory (1989) notes that artificial intelligence has been used to teach subjects such as geography and electronics to students with differing degrees of understanding of the material to be explored. In addition, it can be used to teach students who learn at vastly differing rates or who are at different levels of understanding or both. The Britannica (pedagogy, 2006) cautions that pictures and diagrams, fieldwork, and contrived experiments and observations are all used as a means to the generalizing, abstracting, and explaining that makes up human learning. However, in order to make these processes effective their use must be accompanied by interpretation by an educator.

Bransford, et al. (2000) believe that technologies can help students to visualize difficult-to-understand concepts, such as differentiating heat from temperature. Therefore students may be assisted in their conceptual understanding when they work with visualization and modelling software similar to the tools used in non-school environments. In addition this software may increase the likelihood of transfer from school to non-school settings. Finally, they note that new technologies provide an access to a vast array of information which includes digital libraries, real-world data for analysis; and connections to experts and role models who provide information, feedback, and inspiration, all of which can enhance the learning of students

However, Sierpinska (1994) cautions that it is not possible to teach by means of teaching aids and technology alone. She feels that a better way is for students to verbalise their experiences with the educator and the two parties then ‘negotiate’ a meaning, that is, a maieutic process but one that allows the students the right to choose their own paths of reasoning and to make mistakes. Therefore, teaching aids are merely secondary tools that may be used in this negotiation process. It may be concluded from the above that the educator has to be knowledgeable and experienced for this maieutic process to be successful because there are many ‘language games’ taking place in a social (classroom) setting that can lead to misunderstandings. In addition, students should work in groups and participate in peer discussions in order to consolidate their understanding. However, discussions per se do not necessarily lead to understanding. They must be reflective discussions that are carefully led by an experienced educator.

3.4.2.3 Types of Teaching

Aristotle (1952) taught by means of argumentation. He argued from first principles and sort to refute other people's arguments by pointing out the fallacies in their reasoning, by highlighting paradoxes, by pointing out solecisms, or by showing that the person was merely propounding nonsense, that is, 'babbling'.

Modern institutionalised education tends to be framed to develop a student's knowledge rather than thinking and understanding. However, as discussed above, understanding can be an illusion in the class room situation. In addition, as Sierpinska (1994) notes, the concept of understanding is not the same as knowing, invention or discovery, or the activity of reasoning. Therefore she recommends that learning tasks should be simple, unambiguous but with surprising outcomes for the student. Surprising outcomes force students to modify their thinking. Students should be asked to predict what will happen when changes are made to a system (task) and to explain their thinking. She adds that the teaching of new concepts is only successful if recognition of existing concepts is made and if the new concepts can be shown to be valuable, that is, they solve problems of interest to the student. As Treagust, et al. (1996) note, this type of cognitive conflict is a powerful tool for conceptual change and, in order to aid understanding, ideas and concepts should be seen from as many perspectives as possible.

Teaching must be content specific because learning is content specific. For example, Krygowska (quoted in Sierpinska, 1994) theorises that there are techniques that help in understanding mathematical texts and that these have to be explicitly taught and trained in mathematics classes and not left to the student's own ingenuity. In addition, he adds that understanding mathematics is different to, for example, reading a text because mathematics is a 'forward and backward' process not a linear process like reading.

An approach to teaching that Treagust et al. (1996) believe has gained support is that of contrastive teaching. Contrastive teaching proceeds as follows: (a) prepare standard teaching and demonstration exercises, (b) give the students open ended problems for them to work out questions and hypotheses, (c) students then perform their own calculations, experiments, etc. with little input from the educator, (d) the students' findings are presented to the whole class for discussion and for the educator to point out inconsistencies, (e) the students' results are compared with recognised canonical knowledge, and (f) the students reflect on the problem solving process and method.

Another idea, discussed in the Encyclopaedia Britannica (pedagogy, 2006), that has been mooted for more effective teaching is team teaching. Team teaching represents an attempt to make better use of each educator's potential in their subject area in order to create a flexible learning environment. The Britannica comments that although the team plan may take several forms, it generally consists of the following elements: (a) large-group instruction, in which the total complement of some 50 to 150 students are taught by one educator (either the same educator or several educators in rotation) in a lecture hall; (b) small-group instruction, which alternates with large-group instruction so as to allow small numbers of students and a member of the teaching team to discuss, report, and exchange ideas; (c) independent study, whereby students are given individual projects or library work; and (d) team planning sessions, in which, daily or weekly, the educators plan, coordinate, report on and evaluate their programs.

Finally, Taylor (1996) has commented that educators must work together to set up a new cultural and social paradigm which makes use of critical constructivism and Habermas' concept of communicative action in order to become 'moral' educators. However, based on the ideas of Wittgenstein discussed above this will be difficult in practice.

3.4.2.4 Experience

Teaching via experience has been dealt with in detail above; particularly with respect to the work of Dewey. As mentioned, many educationalists have emphasised the importance of experience in learning and even Wittgenstein (1958) remarked that learning judgement comes only with experience; educators can give one tips here and there but in the end experience is required.

3.4.2.5 Case Studies

For a number of reasons case studies can be effective tools for promoting learning in many areas, including engineering education. First, as Davis and Wilcock (2003) note, traditional teaching methods have been lecture-based in which students are passive recipients of knowledge. However, they continue that recently there has been a move towards more student-centred activities and increasingly more studies indicate that students learn most effectively when involved in active learning. This means that students need to be encouraged to participate in independent study and not just passively receive subject content. Educational research has shown that case studies can be effective in promoting this active participative learning (Grant, 1997; Raju and Sanker, 1999; Chinowsky and Robinson, 1997).

Second, Kolb, (1984) notes that styles and modes of learning differ from student to student, that is, students have different preferred methods for perceiving and processing information. For example, not all students' learning style is suited to that of collaborative study, just as not all students learn best individually. Therefore a learning environment that utilizes a variety of teaching methods and activities is more likely to be effective because it will draw upon a range of learning styles. Furthermore, as Grasha (1996) points out, such an approach may help students to develop their ability to use diverse learning styles and encourage adaptability. Therefore due the nature of case studies they can provide an opportunity to accommodate a variety of learning styles enabling students to develop their technical and key skills without unfairly disadvantaging one student relative to another.

Third, Mustoe and Croft (1999) note that case studies have been linked with increased student motivation and interest in the topic under study.

Fourth, Conway (2001) claims that case studies and active learning techniques allow students to move up Bloom's pyramid of cognitive abilities (knowledge, comprehension, application, analysis, synthesis, and evaluation) enabling them to take part in analytic, synthetic, and evaluative work.

Fifth, the ability to work well in a group is commonly believed to be a valuable skill and one that can be developed. Bonwell & Eison (1991) write that group learning, such as takes place in case studies, can be used to promote active learning; aid the development of communication, leadership, organisation, and problem-solving skills; and Butcher, Stefani, & Tario (1995) note that group learning has clear vocational relevance. However, as Davis & Wilcock caution, students recognise and acknowledge the benefits of group working but many are concerned about potential conflicts and possible uneven workloads within groups.

Sixth, Davis & Wilcock point out that case studies are a good means for encouraging students to undertake independent research outside of the lecture environment and that this can be useful for promoting active learning and self-regulated learning. In addition, case studies require resource investigation which encourages students to utilize a number of different sources and to contact experts in industry.

Seventh, Horton (2001) writes that case studies teach time and project management skills. He continues by noting that case studies, which form part of the course work, require the students to present their work in a variety of formats which usually include oral presentations, articles, posters, and reports. This improves their ability to communicate effectively: a skill which is valued by employers.

As far as the implementation of case studies is concerned Davis & Wilcock point out that formal peer tutoring, where final year undergraduate and postgraduate students are used to facilitate aspects of the case study, can be effective. They continue by noting that peer tutoring is increasingly being used in higher education, with a number of studies promoting it as being a valuable experience for both the students and the tutors (Sobral, 2002; Solomon and Crowe, 2001). Davis & Wilcock claim that this is because in peer tutoring the following facets are found:

- the cognitive processing used to study material for tutoring requires greater depth and understanding compared to that used in studying for a test;
- pear learners benefit from their peer's ability to teach at the appropriate level; and
- both the student tutor and student benefit from the cooperative relationship that peer tutoring creates.

The disadvantages and problems associated with the application of case studies include the following. First, Davis & Wilcock point out that case studies can result in a good depth of learning related to the study topic but the breadth may be reduced because students may not be able to relate the general concepts of a particular case to other examples. Second, they add that it can be difficult to ensure that the case study equates to the same amount of student effort as the teaching activities that it replaces.

Third, Davis & Wilcock write that to prevent students copying from the internet and undertaking surface learning, they should be provided with references that they are expected to consult. In addition, it must be made clear to the students that they are expected to critically analyse their work.

3.4.3 The Educator as a Guide

It is generally accepted that knowledge is something one gets slowly on one's own, that is, one moves slowly from becoming to being. Many modern educationalists would probably agree with this sentiment since much current educational thought views the educator as a guide. This section emphasises the importance of an educator's subject knowledge and pedagogical knowledge.

3.4.3.1 Educator Knowledge

It is obvious that effective educators need pedagogical knowledge; that is, knowledge about how to teach in particular disciplines, which is different from knowledge of general teaching methods. However, as Bransford, et al. (2000) have noted, expert educators need to know the structure of their disciplines so that they have cognitive roadmaps that guide the assignments they give students, the assessments they use to gauge student progress, and the questions they ask in the give and take of classroom life. In short, educators' knowledge of the discipline and their knowledge of pedagogy interact. However, they continue that knowledge of the discipline structure does not in itself sufficiently guide an educator. Expert educators need to be sensitive to those aspects of their discipline that are especially hard and especially easy for new students to master. As Treagust, et al. (1996) commented, educators need a broad knowledge of the subject matter in order to aid students to construct their own knowledge. This emphasis on interactions between disciplinary knowledge and pedagogical knowledge, in Bransford, et al.'s view, directly contradicts a common misconception about what educators need to know in order to design effective learning environments for their students. The misconception is that teaching consists only of a set of general methods and that a good educator can teach any subject: that is, content knowledge alone is sufficient.

Finally, Bransford, et al. note that in the context of the university, basic researchers, for the above reasons, often have a poor understanding of why students fail to grasp basic concepts of a particular discipline, that is, the researchers do not realise which concepts are difficult and which are easy. On the other hand educators without a good disciplinary knowledge often fail to see relationships between core concepts that, if better understood from the standpoint of theory, could facilitate their teaching. Therefore a more effective contact between pure researchers and educators in a particular discipline would be advantageous.

3.4.3.2 Free Market for Educators

A number of thinkers, such as Adam Smith (1990) and Milton Friedman (1962), have been of the view that the most effective way to improve the quality of teaching is to place the teaching profession in an economic free market. That is, educators' salaries should depend on their performance because, Smith and Friedman claim, if they have fixed salaries they will spend as little time on teaching as possible and use their time for other things. In addition, educational managers cannot coerce educators to teach well and educators will teach well only if they benefit from teaching well. This idea is substantiated by the excellent results produced by many private competitive teaching institutions such as music schools and art colleges. In addition to competitive salaries Smith pointed out that some mechanism should be established that allows students to choose their educators. However, this process if not managed correctly can produce unwanted results. For example, Weber (1946) noted that university courses that are popular and draw large crowds are not necessarily good courses because students are often attracted by an educator's personality rather than by the real course content, that is, students crave a leader and not an educator but few academics are real leaders. In addition, Smith believed that an added benefit of a competitive market for teaching would be that discipline would be 'natural' due to good teaching and not forced on students for the benefit of educators.

However, in the field of engineering, compulsory professional qualifications, as determined by the Washington Accord (2003), prevent private institutions from easily setting up in competition to 'registered' institutions because their graduates will not be able to become professionally recognised. This reduction in competition is another possible reason why the pass rate in engineering education is so low.

3.5 Conclusions

It is clear from the above that most 'modern' educational ideas have a long history and that much of the educational research in the 20th century has merely re-invented the 'wheel' or more closely defined the 'wheel'. Concepts such as conditioning, the importance of prior knowledge, experience based education, the idea of students constructing their own knowledge, radical constructivism or solipsism (in the form of Descartes' *cogito ergo sum*), discovery learning, the idea of knowledge being socially mediated, integrated assessments, the importance of a good educational environment, the importance of educators having discipline knowledge, and the idea of a free market for educators have, in most instances, been around since the time of the ancient Greeks. It is therefore unfortunate that educationalists did not use these ideas as starting points for their research rather than merely rediscovering these ideas in the 20th century.

Ideas that are new to education, such as team teaching, are rare. However, a 20th century thinker that has had many original ideas is Wittgenstein. In particular, Wittgenstein's ideas of understanding not being a mental process but a mental event and the impossibility of a private language highlight the fact that much of the learning and teaching theory listed in the above sections is either meaningless or difficult to implement. The conclusion that may be drawn from Wittgenstein's work is that one does not know how understanding takes place and neither does one understand how the creative use of understanding is fostered. This may explain, as mentioned above, why mathematics teaching has not improved much during the 20th century. It may also explain why the failure rates in engineering courses, mentioned in chapter one, are so high. Furthermore, much education in the passed has involved rote learning and rule following. This is probably due to the fact that is easy to facilitate these processes and they can be easily assessed.

Therefore, the only way for educators to increase the probability of understanding taking place is for them to approach a topic with the students in as many ways as possible, to assess the students in as many ways as possible, and to be good role models. This is done with the hope that the plethora of approaches will trigger some understanding of the topic in the students and that the many types of assessments will give the educator some insight into how much the students have actually understood. There is no sure way of ensuring that a particular student will understand a particular complex topic or of completely assessing that student's understanding of the topic. In addition, it is essential that schools provide students with the basic skills and attitudes that they will need to benefit from this range of approaches to a topic. That is, the schools must ensure that students can read, write, are numerate, know the basic rules of logic, and have a good attitude to learning.

Finally, if knowledge is socially mediated truly creative people will have difficulty because, by definition, they are producing ideas that the rest of society is unaware of and in many cases is unlikely to accept or appreciate. Kuhn (1970) has dealt with this idea in detail in his book ‘The Structure of Scientific Revolutions. A classic example of this phenomenon is that of van Gogh and his ideas on painting mentioned above.

All of the above ideas and concepts will be returned to and utilised in chapter five in which the structure of the engineering syllabus is discussed.

CHAPTER 4
THE CURRICULUM

4.1 Introduction

This chapter begins with a discussion of some of the key historical ideas that have determined the arrangement of studies. It then looks at the developments that have taken place during the 20th Century and ends with a discussion of the latest ideas relating to curriculum design and the effects of curriculum design.

The idea of the curriculum as a significant field of study is a relatively new development. As the next section shows, historically the order of study and the topics to be studied remained fixed for long periods of time with few changes. The ancient thinkers never thought of the curriculum in the modern sense, rather they were interested in what type of background knowledge it was necessary to have in order to educate oneself and to obtain more advanced knowledge and what methods were effective for developing this advanced knowledge. In medieval times work skills were usually obtained in artisan guilds in which the ‘trainee’ artisan would watch a skilled craftsman work and would gradually take on more and more complex tasks (guild, 2007). Medieval universities had a rigid course structure which consisted of an introductory level of study called the trivium (grammar, logic, and rhetoric) which was then followed by more advanced studies called the quadrivium (arithmetic, geometry, astronomy, and music (mathematical arts)) (Pinker, 1999).

4.2 Some Aspects of the History of the Curriculum

4.2.1 Ancient History

4.2.1.1 The Order of Studies

Although historically the order of studies has remained fixed for long periods the importance of the order of studies has been debated for many centuries. For example, in the Gorgias, Plato (1875) has Callicles asserting that philosophy is good and necessary for youths but grown men must partake of the 'busy centre and the market place'. Callicles adds that philosophers don't know how to defend themselves if they are threatened, for example, in court and that they should emulate 'only the man of substance and honour, who is well to do'. In the Republic Plato responds that this view is incorrect and that philosophy is the highest and most important form of study, that is only philosophers should be allowed to rule.

In fact, Plato discusses the order of study in many places in his works. For example, in the Sophist he states that before discussing something one should define ones terms and that the discussion of a topic should start with the 'lesser and easier instances' before one proceeds to the greater. Aristotle (1952) was of a similar opinion when he stated in Physics that in the science of nature, as in other branches of study, the starting point is to try to determine its primary conditions or first principles and that one should start an investigation from things which are easy to know and then move onto the more obscure things. That is, one should move from generalities to specifics. In Metaphysics he noted that one should start ones studies 'from what is knowable to oneself and make what is knowable by nature knowable to oneself' (p. 1029). In other words, Aristotle foresaw the emphasis that modern learning theory puts on knowing the students level of prior knowledge before proceeding with further studies.

According to Hobbes (1990) in the Leviathan the fields of knowledge may be divided into the following divisions which still hold to a large extent in the 21st century: primary philosophy, mathematics, astronomy, geography, science of engineers (bodies in motion, figure of bodies, weight, etc), architecture, navigation, sciography, astrology, optics, music, ethics, poetry, rhetoric, logic, and the science of the just and unjust. In addition, Hobbes makes the unusual claim that philosophy should be grounded in geometry. Perhaps what he is saying here is that philosophy must not lose touch with the real world. Hence geometry, or reality based subjects like physics, should be taught first and only once students have mastered them should they move on to philosophy in the modern sense of the word.

Rabelais (1990) recommended that in order to be properly educated one should learn the following: Greek, Latin, Hebrew, Chaldee (Aramaic), and Arabic; history; cosmography; geometry, arithmetic, and music; astronomy; civil law; philosophy; nature (that is, study animals, plants, and minerals); medicine and anatomy; the Holy Scriptures. In the practical world, Rabelais recommended that one should learn about chivalry, warfare, and exercises of the field in order to protect one's self and one's family.

A 17th century thinker that had some definite ideas on how knowledge is obtained, and the order in which it is obtained, was William Harvey (1990). He stated that there is one road to scientific knowledge: one proceeds from things more known to things less known, from matters more manifest to matters more obscure. Science springs by reasoning from universals to particulars; however the comprehension of universals by the understanding is based on the perception of things by the senses. Often particulars become universals after being perceived, for example, the colour yellow. While it is being perceived it is a particular but later the memory of yellow becomes a universal. Furthermore he stated that 'without the due admonition of the senses, without frequent observation and reiterated experiment, our mind goes astray after phantoms and appearances' (p. 334). That is, one should strive after personal experience rather than rely on the experience of others. One should try to take nothing on trust because when others communicate their experiences the reported experience is never a true representation of the original sense experience. In addition, personal experience enables one to develop good judgement. Harvey was also of the view that there is no such thing as innate knowledge. He believed that all knowledge, even reasoning, is acquired. He also noted that the method in which an art or science is acquired is as follows: the thing perceived by sense remains; from the permanence of the thing perceived results memories; experience comes from having many sense memories; and from experience, from universal reason, from definitions, and from maxims (or common axioms), the most certain principles of knowledge result. Finally, he stated that in all subjects upon which information is desired inquiry must be begun from the causes, especially the material and efficient ones and that one may use historical knowledge but that it should treat it with scepticism and caution.

In the Advancement of Learning, Bacon (1990a) put forward a number of modern ideas on how knowledge and learning may be progressed. In particular, he noted that to study something one should study its parts rather than try to study it as a whole, that is, it should be broken down into pieces that may each be well understood before continuing to the next piece. However, he did recognise that generally people prefer to studying subjects like history and literature rather than 'dry' subjects like logic and mathematics.

Adam Smith (1990) summarised the historical approach to the curriculum when he wrote that education in ancient Greece and Rome appears to have been 'laisser faire' and that each family seems to have 'done their own thing' with no compulsion from the state other than to become good soldiers (physically). Traditionally the material taught in universities in Europe was dominated by religious concerns with the result that a proper study of the natural world was neglected. Hence, 'logic was taught first; Ontology came in the second place; Pneumatology, comprehending the doctrine concerning the nature of the human soul and of the Deity, in the third; in the fourth place followed a debased system of moral philosophy which was considered as immediately connected with the doctrines of Pneumatology, with the immortality of the human soul, and with the rewards and punishments which, from the justice of the Deity, were to be expected in a life to come; and finally a short and superficial system of Physics usually concluded the course' (bk. 5). In contrast, Smith made the observation that in his era most systems of philosophy, morals, etc, that is speculative systems, tend to take a subservient role to common sense when a pecuniary interest is involved. (Interestingly he was also of the opinion that one should not go travelling when one is too young, that is under the age of 28, because one tends to waste the time in frivolous activities which weaken rather than strengthen one's true education. This contradicts the modern idea of the value of the OE.)

Veblen (1899) had similar views to Smith. In The Theory of the Leisure Class he stated that the exigencies of modern industrial life have forced mankind away from knowledge for knowledge's sake, and the classics, etc to a greater recognition of the importance of the hard sciences. (He also believed that scientists often come from the leisure-class with middle or upper middle class backgrounds rather than from the long-term leisure class.)

Thinkers such as Samuel Johnson did not believe in the idea of a formal curriculum for their own studies. He read widely but in a fairly disorganised way although he did try to organise the reading that he undertook. He did, however, believe that one should get into the habit of regular study otherwise one becomes lazy and study becomes difficult to get back into. In addition, he had a high regard for the study of civil law and ancient languages (Boswell, 1990).

After his visit to the United States of America in 1831 Tocqueville (1965) developed some strong views on what type of curriculum should be taught in schools. He felt that it was clear that in democracies individual interests and those of the state demand that education for most people should be scientific, commercial, and industrial rather than literary. Greek and Latin should not be taught in all the schools. However, he believed that it was important that those who are destined by nature or fate to adopt a literary career or to cultivate such tastes should be able to find schools where the classics are well taught and true scholars formed. He added that the classics are important in a democracy because they were created in a different political environment, for example aristocracy, and therefore provide an alternative insight into social structures, and even the classics themselves show structures and methods of writing that are influenced by the society in which they where created.

Goethe (1959) believed that before studying any particular field one should learn logic and metaphysics first. However, this recommendation requires caution because this was the advice of Mephistopheles in Faust!

Alfred North Whitehead (1911) had a deep understanding of mathematics and was of the firm opinion that in order to learn something like mathematics a student must not get bogged down in details and processes before they have a general conception of where they are going. Students should be enabled 'from the very beginning of their course to know what the science [mathematics] is about, and why it is necessarily the foundation of exact thought as applied to natural phenomena' (p. 125). He also believed that to teach what something is about one must start with concepts that the students know and understand as is common in current educational thinking.

4.2.1.2 The Value and Transferability of Studies

A second type of debate which also has a long history is the debate about the value of particular topics of study and whether the knowledge gained by studying one topic is transferable to another area of study.

In the Sophist Plato (1875) stated that all the arts [in the Platonic sense] are either acquisitive (learning and cognition, trade, fighting, hunting, etc.), or productive or creative (agriculture, tending animals, construction, moulding, etc). In addition, in the Laws he presented the view that music and dance can have a good or a bad influence on people depending on how they are taught and used.

Nicomachus (1926) believed that arithmetic teaches one about absolute quantity, music about relative quantity, geometry about stationary 'sizes' and astronomy about moving 'sizes', and that it is necessary to know about these things in order to deal with being, to discover truth, to become wise, and to philosophise properly. He added that these studies are like 'ladders and bridges' that carry our minds from things apprehended by sense and opinion to those comprehended by the mind and understanding, and from those material, physical things to the things with which we are unacquainted, foreign to our senses, but in their immateriality and eternity are more akin to our souls. Therefore, of all the things that may be studied, the most fundamental and therefore the topic that must be studied first is arithmetic.

In the Almagest Ptolemy (1948) agreed with Nicomachus since he stated that one should study mathematics because it is fundamental, certain, and unchanging; unlike theology which can not be known for certain.

Epictetus (1990) had similar views, but with respect to logic, because he noted that logic is necessary to show contradictions and to prevent being cheated in an argument. In other words, once one knows that something is contradictory one will stop doing it because it will not be to one's advantage.

In the Advancement of Learning Bacon (1990a) stated that theory must be put into practice before it becomes useful and can be confirmed. In addition, in the Novum Organum he noted that scientists often get little reward for advances that they make. It is usually the people who market and sell these advances that get the reward; which can be demotivating for the scientists (Bacon, 1990b).

Adam Smith (1990) believed that basic studies were important. He stated that reading, writing, and accounting (arithmetic) are the most important parts of one's education. In addition, he commented that 'the more they [the people] are instructed the less liable they are to the delusions of enthusiasm and superstition which, among ignorant nations, frequently occasion the most dreadful disorders. An instructed and intelligent people, besides, are always more decent and orderly than an ignorant and stupid one' (Smith, 1990, p. 385).

4.2.1.3 Knowledge and Understanding

Saint Augustine (1873) believed that before one could begin a curriculum of study, in fact before one could undertake any serious study, it was necessary to have a good background of knowledge and understanding. The background knowledge that he believed was necessary before any serious field of study could be undertaken was the following. First, he believed that a background in history is useful and that a working knowledge of the mechanical arts (building, medicine, agriculture, etc) is useful for developing understanding. That is, a person should have a general knowledge and the more extensive it is the better. Secondly, he believed that logical reasoning and the avoidance of excessive ornamentation (in speech and writing) are useful for obtaining and refining knowledge. However, Augustine claimed that logic and mathematics were not human constructs but were divinely inspired by God. Furthermore, due to his religious bias, he noted that although knowing the laws of inference for drawing conclusions was useful it is still better to have 'true' opinions about things without having to obtain them using logical reasoning, that is he believed that real knowledge is divinely revealed. Thirdly, he believed that rhetoric and dialectic are useful for setting forth the truth but often a clever man will perceive the truth even if he doesn't know the rules and techniques of rhetoric and dialectic. Finally, he believed that one must make sure that one's learning is of use (broadly defined) and is not learning for the sake of learning, and one must use reliable knowledge from whatever source, without prejudice, to help one to further one's knowledge.

Hobbes (1990) wrote extensively about knowledge and, by implication, understanding in the Leviathan. He noted that there are two kinds of knowledge: knowledge of facts and the knowledge of the consequences of one affirmation to another, that is, inductive logical reasoning. For example, books of 'philosophy' contain the demonstrations of consequences of one affirmation to another. The first type of knowledge is based on sense and memory; and the latter is 'science' and is conditional, that is, it has the structure of, *if this then that*. The second type of knowledge is also traditionally the knowledge of 'philosophers'. Hobbes added that the record of the knowledge of facts is called history of which there are two sorts. Natural history which is the knowledge of facts of nature and these do not depend on humankind's will. The other is civil history which is the voluntary actions of humans in 'commonwealths'.

Bacon (1990b) also wrote extensively about human knowledge. For example, in the Novum Organum he wrote that few notions that humankind has are soundly based. One tends to take a small amount of evidence for something and then deduce all sorts of general axioms from this evidence using logic rather than more experimentation and investigation. The only path to true knowledge is via careful observation, thorough experimentation, and the investigation of actual things. He added that humankind has four causes of false notions: errors due to the senses and incorrect thought processes; errors due to individual prejudice; errors due to following the 'herd'; and errors due to being enmeshed in particular philosophies. Bacon, however, had a rather jaundiced view of religion and educational institutions. He wrote that religion and superstition have often been an opponent and a hindrance to science and truth. Further, it should be impossible for science to be a danger to religion if religion is truly divinely inspired. As for educational institutions, he noted that they are often also a hindrance to the advancement of knowledge because they use their authority to push their views and to bury different or opposing views. In general he commented that one must be encouraged to keep working towards the advancement of knowledge and to not give up the hope that advances can be made and the hope that all the hindrances to advancement can be overcome.

A 17th century thinker who had a profound influence on the ordering and development of knowledge in the western world was Descartes (1969b). In Rules for the Direction of the Mind he wrote that one needs a method for finding out the truth so that one will never assume what is false as true, and will never spend mental effort to no purpose, but will always gradually increase one's knowledge and so arrive at a true understanding of all that does not surpass one's powers. He noted that one gets knowledge in three ways only: via intuitive understanding and memory, via the imagination, and via the senses. However, real understanding ultimately determines the truth or falsity of something. He believed that dialectic may be used to firm up knowledge but it does not create new knowledge, that is, knowledge comes only from the 'pure light of reason'. Descartes was of the view that pure mathematics (order and measurement) was a good starting point for beginning to obtain knowledge because pure mathematics requires mental intuition and deduction. However, he said that to obtain true knowledge one must reduce involved and obscure propositions step-by-step to those that are simpler, and then starting with the intuitive apprehensions (immediate understanding) of all those propositions that are absolutely simple, attempt to ascend to the knowledge of all others by precisely similar steps. In order to separate out what is quite simple from what is complex, and to arrange these matters methodically, one ought, in the case of every series in which one has deduced certain facts the one from the other, to notice which fact is simple and to mark the interval, greater, less, or equal, which separates all other facts from this fact. In addition, he noted that one must always start by understanding the fundamentals of any study well, that is start with the most insignificant and most easily mastered facts and master them first. Once this has been done then, and only then, ease into more difficult topics. Further, one must know one's fundamental knowledge thoroughly so that one can derive all else from the fundamentals and so that one can really understand all else. He was also of the view that one should continually undertake a 'meta-analysis' of one's problem solving so that one can develop a series of patterns of problem solving that one may use to solve new problems or discover new truths.

Descartes recognised that one does not always have complete knowledge of a topic. He wrote that when one is investigating a line of knowledge one can continue the investigation based on incomplete knowledge. However, 'if in the matters to be examined we come to a step in the series of which our understanding is not sufficiently well able to have an intuitive cognition, we must stop short there' (rules 8-11). In addition, he emphasised that knowing when a certain investigation can not be taken any further, that is the limit to knowledge, is as valuable a piece of knowledge as finding out something new. To increase one's knowledge Descartes believed that two faculties of mind were necessary, that is, the ability to see single 'objects' distinctly, and the ability to make skilful deductions of certain facts from others. All sciences begin with what is easy and more readily understood. That is, 'in order that it may acquire sagacity [make sound deductions] the mind should be exercised in pursuing just those inquiries of which the solution has already been found by others; and it ought to traverse in a systematic way even the most trifling of men's inventions though those ought to be preferred in which order is explained or implied' (rules 8-11). That is, one must get plenty of practice in easy to follow, logically structured, simple topics before one starts studying more complicated topics, for example, derivations are important particularly if they are studied in a well structured format. Finally, he saw that by constantly revising the steps and structure of fundamental knowledge one will be help one to see the structure of more complex problems.

Descartes realised that, “once a ‘question’ is perfectly understood, we must free it of every conception superfluous to its meaning, state it in its simplest terms, and, having recourse to an enumeration, split it up into the various sections beyond which analysis cannot go in minuteness” (rule 11). However, he noted that to solve a ‘question’ one must ‘explore in an orderly way all the data furnished by the proposition, to set aside everything which we see is clearly immaterial, to retain what is necessarily bound up with the problem, and to reserve what is doubtful for a more careful examination’ (rule 13). In addition, one must not assume more or less than the data furnish, and one must not leave anything out that is relevant. Finally, he advised that one should not believe anything too certainly of which one has been convinced only by example and custom.

As William James (1890) noted, with respect to the development of knowledge, we initially sense things as a continuous whole and later, using mental effort, break the thing down into separate (discriminated) aspects. With the result that the more we analyse something the more we find differences. He added that ‘the first sensation which an infant gets is for him the Universe. And the Universe which he later comes to know is nothing but an amplification and an implication of that first simple germ which, by accretion on the one hand and intussusception on the other, has grown so big and complex and articulate that its first estate is unrememberable’ (p. 454).

4.2.1.4 Learning to Think

Plato's (1875) method of teaching students to think was to involve them in probing discussions. He stated, in the Gorgias, that to have good discussions one's interlocutor should be knowledgeable, have good-will, and be outspoken.

Augustine (1873) stated that to learn something one must get an overall picture first and then go into the details, that is, use well understood sections to throw light on the more obscure sections. Contrary to many modern approaches to curriculum design however, Saint Augustine added that a good memory is necessary in this process. As far as the actual process of furthering knowledge is concerned Augustine stated that it is important and useful to know how to define, divide, and partition knowledge. Furthermore, since much of our knowledge comes from reading text he emphasised that in reading one must remember that terms often have literal *and* figurative meanings, and to interpret figurative expressions a good general knowledge is required, that is, of animals, arithmetic, music, etc. In addition, one should always try to read texts in the original language, although a range of translations can throw light on obscure texts by giving different points of view and interpretations. It is particularly important to know other languages in order to throw light on figurative expressions which usually do not translate well. In conclusion, Augustine had a modern view of how knowledge is constructed and socially negotiated because he stated that much canonical knowledge is regarded as knowledge because a large number of authorities, that is, the hierarchy of the Catholic Church, regard it as knowledge.

Hobbes (1990) did not believe that mere experience was valuable for learning to think because experience is the memory of a succession of events in times past and is not found from reasoning (for example, animals learn by experience) and a slight modification of the past events will give different results causing confusion. Therefore, according to Hobbes, only correct reasoning produces general, eternal, and immutable truth. Fundamentally, Hobbes' views are like those of Wittgenstein (2004) in that he also believes that 'the world is all that is the case' and that little can be said about anything else.

Rabelais (1990) believed that in order to learn to think clearly one should speak according to the common language and shun all strange and unknown words, that is, do not use jargon and unnecessarily complicated forms of expression. In addition one should try to defend one's ideas in public debate; one should seek the company of learned men, that is, role models; one should serve, love, and fear God; one should not be vain or malicious; one should love one's neighbour as oneself; one should shun the conversation of those one does not want to resemble; and one must not waste one's natural gifts.

Bacon (1990a) had definite ideas on how one should learn to think. He stated in the Advancement of Learning that there are four intellectual arts: the art of inquiry or invention, that is doing something; the art of examination or judgement, that is to judge what is done; the art of custody or memory, that is to retain what is judged; and the art of elocution or tradition, that is to comment on what is judged. He stated that he agreed with Plato's opinion that whoever looks for knowledge knows what she is looking for in general because how else will she know when she has found it? Therefore, the larger one's anticipation is the more direct and compendious will one's search be. That is, one should have a good knowledge of fundamental principles and the basics if one wants to create, discover, or understand something new … 'ars inveniendi adolescit cum inventis' - the art of invention grows with inventions themselves (p. 59). Bacon continued in the Advancement of Learning by stating that one must not be led astray by metaphysical arguments, incorrect impressions, or by not properly defining one's terms. That is, one must take care to learn the rules and proper uses of logic and argument. He noted that arguments may be demonstrated in four ways: by the consent of the senses, by syllogism, by induction, or by congruity (agreement). In addition he was of the view that the use of language and grammar are an important part of knowledge and learning.

Locke (1690) had a number of ideas on how people learn to think and how they improve their thinking. He stated that '*external* objects furnish the mind with the ideas of sensible qualities, which are all those different perceptions they produce in us; and the *mind* furnishes the understanding with ideas of its own operations'

(p. 122). In addition, he believed that as people mature they move from being dominated by their perceptions of the external world to becoming more reflective.

Locke understood that in order to think clearly one should always know what one's terms mean and define one's terms thoroughly. Many other thinkers also believed it was important to define one's terms, for example in The Brothers Karamazov Dostoevsky (1968) stated that **'**before you talk of a historical event like the foundation of a nationality, you must first understand what you mean by it' (p. 305). However, although to start from a set of axioms has been successful in mathematics Locke did not believe this approach could be used in other fields, instead one must compare clear and distinct ideas and beware of building on precarious 'principles' that can not be justified. In general, axioms (maxims) may be useful for teaching but they do not help to further knowledge. Now Locke noted that in order to understand the nature of the terms that one is using one must realise that general terms such as 'man' are just specific terms such as John with all the particular aspects that apply only to John removed. He added that complex ideas such as *justice* are usually known by an individual before they are fully defined by that individual to himself, whereas simple ideas are usually the reverse. However, because complex ideas like justice are not linked to anything physical they are hard to define and people interpret them in a myriad of ways. In general, Locke noted that the knowledge of something usually moves from knowledge of the particular to knowledge of the general.

Adam Smith (1990) had great confidence in the thinking ability of mankind when he commented that gross sophistry has little effect on the principles and thoughts of the majority of humankind. However, as current world events show, it is dubious whether this is true.

Samuel Johnson was of the view that one learns to express oneself by reading and imitating the best authors. Johnson thought that the reading of the classics in the original languages was important for one's education. However, he did not justify this thought. He did however believe that an education should be matched to the student, that is don't try to make a child wise beyond its years and that much learning takes place by emulation rather than from formal lessons. Johnson also believed in fairly rigid discipline for young students (Boswell, 1990).

4.2.2 Early 20th Century

4.2.2.1 Introduction

A major development took place in the nineteenth and early 20th century when attempts were made to specify the educational goals that students had to achieve in order to be regarded as having attained a particular level of education. However, these specifications concentrated on general goals that meant different things to different educators. The vagueness of these goals stimulated psychologists to devise taxonomies of specific, clearly stated objectives in each of three domains: cognitive, affective, and psychomotor (Biehler & Snowman, 1997).

4.2.2.2 Learning Objectives

Bloom (1956) and several associates prepared the six level taxonomy for the cognitive domain consisting of knowledge, comprehension, application, analysis, synthesis, and evaluation. The taxonomy for the affective domain was devised by Krathwohl, Bloom, & Maisa (1964) and it has five levels: receiving, responding, valuing, organising, and characterization by a value or value complex. Simpson (1972) devised the taxonomy for the psychomotor domain which is composed of seven levels: perception, set, guided response, mechanism, complex or overt response, adaptation, and origination.

Mager (1984) states that well-written objectives should specify what behaviours the student should exhibit to indicate mastery of a particular objective, the conditions under which the behaviour will be shown, and the criteria for acceptable performance. However, Gronlund (1995) believed that complex and advanced kinds of learning do not lend themselves to Mager type objectives. Complex objectives are usually so broad in scope that it is impractical to ask students to demonstrate everything they have learned. Instead, Gronlund suggests that educators first state a general objective and then specify a sample of related outcomes.

As Biehler & Snowman (1997) note, formulating objectives helps one to plan a logical sequence of instruction, they provide one with ideas for classroom activities and remedial instruction, and they help one devise tests that will determine if learning has occurred. Objectives work best when students are aware of them and understand their intent, and when they are clearly written. They seem to work particularly well when they are provided to average students for tasks of average difficulty and when intentional learning is measured.

Biehler, et al. continued that one of the problems with learning objectives is that most educators use test questions that measure knowledge-level objectives and largely ignore higher-level outcomes. A second problem is that there is some evidence that learning objectives seem to work best with average students but seem to be overly constraining for good or excellent students.

Finally, Biehler, et al. commented that outcome-based education is an institution-based and industry-based approach to providing instruction that begins by specifying important educational outcomes, or objectives. These objectives then provide a guide for curriculum construction, the course length, and the sequence of courses. Although a variety of instructional methods are compatible with the practice of outcome-based education mastery learning is almost always made a part of it.

In order to overcome the above problems Tyler (1949) and Mager (1975) believed instructional objectives should be complete and specific, that is they should use words like *describe, identify, and solve;* and not words like *understand, be familiar with, and appreciate.* However, they often limited the specification of objectives to those which could be measured quantitatively and which described discrete forms of student activity. Eisner (1994) and Stenhouse (1975) criticised this approach to instructional objectives by noting the following:

- Many educational performances involve the analysis and synthesis of information from diverse sources, creativity, understanding, aesthetic appreciation, and problem solving which are not directly measurable.

- The educational objectives that are hard to measure, will be under emphasised in a curriculum designed using instructional objectives. That is, acquiring information will be emphasised over understanding. It is often assumed that the achievement of an objective implies mastery of the objective. However, only relatively trivial knowledge and skills are capable of complete mastery whereas higher level skills can be improved continuously throughout one's life.

- Tightly specified objectives will limit an educator's ability to take advantage of educational opportunities that arise in the classroom.

- Separately specified objectives can mitigate against students learning to synthesise knowledge from different areas.

- Qualities such as creativity, insight, integrity, self esteem, and understanding are not goal directed but are often exploratory and are therefore are not easily specified as objectives.

Although educational objectives do have the above limitations, they have played a positive role in that they moved the focus of curriculum design from the content of the curriculum to students and their learning. That is it forced educators to think about what they wanted students to achieve (Toohey, 2002). A number of researchers have suggested adding higher level skills to the curriculum objectives such as problem-solving objectives and expressive objectives, or putting more emphasis on the process of learning rather than the product (Eisner, 1994; Stenhouse, 1975; Rowntree, 1981; Allan, 1996). However these ideas have not been widely adopted because they are difficult to define, to teach, and to assess (Toohey, 2002).

To overcome the above problems Lovat and Smith (1995) developed the work of Habermas (1972). Habermas had postulated that the three different kinds of human interests result in distinctly different kinds of knowledge or understanding as follows:

- The interest in controlling or mastering one's environment leads to the development of technical, empirical, and conventional knowledge.
- The interest in developing shared understanding with others, in communicating, and in negotiating meaning leads to interpretive or hermeneutic knowledge.
- The interest in freedom from unthinking acceptance of social and political systems, and individual limitations leads to the development of self-reflective and critical understandings.

Lovat and Smith then theorised that people seek knowledge in response to these three different interests. The drive to satisfy these interests produces different kinds of knowledge and hence different implications for curriculum design, teaching, and assessment.

Toohey (2002) wrote that the type of knowledge that enables one to control the world in which we live is empirical and technical knowledge which includes many techniques and skills. In these areas most educators require their students to attain mastery. However, technical and empirical knowledge never constitutes the whole of a discipline not even in the science and engineering disciplines. To specify and assess these types of learning classical behavioural objectives and conventional testing can be used.

She continued that the type of knowledge that allows one to communicate and understand one another is usually obtained dialectically in group discussions. The learning objectives for this type of knowledge will be the requirement that the students learn a process, a methodology, a logical way of thinking and arguing, and how to find and evaluate sources. Due to the nature of these objectives their assessment will be more subjective than those mentioned in the above paragraph.

According to Toohey, self-reflective objectives that promote individual autonomy and freedom are the most difficult to specify because this knowledge is gained through meditation, reflection, challenging personal experiences, and understanding derived from being part of a particular cultural group. Clearly this type of learning can not be assessed objectively because it deals with personal individual development.

Finally, she noted that for objectives have any degree of success they are required to have the following characteristics:

- They must represent real goals, that is, the goals must not be trivial but should tell a student what they should be able to do differently as a result of their education.
- Learning objectives must place academic skills or personal learning in the context of the particular subject matter in hand. That is they should, for example, specify what is meant by critical thinking or communication skills in engineering.
- Learning objectives should include a description of the kind of performances by which achievement will be judged. That is, is it important that a student learn a particular skill or is the skill to be learnt in order to provide an indication of the student's level of understanding.
- Learning objectives should allow for either mastery or progress depending on the nature of the learning. That is, does the learning involve technical mastery or does it require the students to become more experienced in the processes which lead to a greater depth of understanding and creativity.
- Learning objectives should be memorable and limited in number so that students and educators can keep them in mind throughout the course.

4.3 Current Ideas about the Curriculum

4.3.1 Introduction

Although the ideas, from the first part of the 20th century, of using learning objectives and goals, are still widely used for designing educational curricula the view of the curriculum has become more sophisticated over the last few decades. This increase in sophistication is thoroughly discussed in the book by Susan Toohey (2002).

Toohey begins by making the distinction between deep study and superficial study by quoting the work of Entwhistle (1981) and Biggs (1987). She presents the fairly obvious conclusion that students who study deeply and understand the work are more successful and those that undertake superficial studying do not do as well. The main reasons given for undertaking superficial study are time pressures and an assessment system that does not encourage deep study (Gibbs, 1992; Biggs, 1995). Students who do not learn deeply 'hope that in future, when [they] are required to use their knowledge in professional practice or in further study, they will remember that it was touched on in their introductory units and will know where to start looking for information when they have to learn about the topic … this time for real' (Toohey, 2002, p. 14). Biggs (1989) notes that in order to encourage deep learning the following contributory factors are necessary: an appropriate motivational context, a high degree of student activity, interaction with others (both peers and educators), and well structured knowledge base. And Toohey (2002) notes that good teaching is not what the educator does but what the students are required to do.

In addition, Toohey makes the comment that one must not let market pressures reduce the quality of tertiary courses because then the whole point of tertiary education, such as critical thinking, analysis, problem solving, and new knowledge creation, will be compromised. However, I feel that in the modern capitalist societies this would be difficult to achieve.

Based on the above comments Toohey states that the two central questions in course design are: what is important for students to know, and what is the best way for them to learn it? Subsidiary questions resulting from these questions include the following:

- What is it that characterises knowledge in the discipline or profession being studied?
- How does learning occur and how is it best facilitated, that is, what should be the role of educators and what should be expected of students?
- What goals and objectives are worthwhile, and how are they best expressed in order to promote the type of learning aimed for?
- What content must be included, how should it be organised, and what might be left for students to learn in other ways?
- What is the role of assessment and what forms should it take?
- What resources and infrastructure will be needed to achieve the above?
- Who else has a legitimate interest in this curriculum? For example, what is the relationship between the faculty and professional associations, the funding bodies, and the university itself?

Therefore, to summarise Toohey's recommendations, the curriculum of a tertiary course should primarily be aligned with the needs of the student, and secondly with the needs of the community and the direction being taken by the profession. Its teaching goals and purposes, the choice of teaching and learning strategies, and assessment methods should be made clear to all those involved in designing the curriculum, in teaching the curriculum, and to the students. Finally, curriculum designers need to honestly evaluate their beliefs about education and teaching and learning to be aware of how these beliefs are biasing their curriculum design.

A far as the actual curriculum content is concerned a number of researchers and organisations have produced lists of ability statements for the engineering curriculum. McCowan (2004) has listed numerous professional, academic, governmental, and employer bodies that have studied engineering and engineering education (ACEC, 1994; ASEE, 1994; CAE, 1997; CAE 1999; Felder, 1993;

Heitmann, 1995; Meyers and Ernst, 1995; NAS, 1995; Simmons, 1995, 1996). Interestingly, he notes that despite the fact that these reports reflect the situation in different countries and despite the fact that they were undertaken by widely differing groups, their conclusions have remarkably common themes, particularly regarding the need for engineers to acquire a broad range of professional skills.

For example, Maillardet in Baille and Moore (2004) has noted that engineering consists of mathematics, science, and techné (the ability to conceive, design, make, and actually bring engineering objects to fruition). That is, the essential *creativity* at the core of engineering must be apparent in all that the profession shows to the world at large. In addition, Maillardet lists the generic abilities that engineers must have according to the Engineering Professors' Council (EPC) in the United Kingdom. These abilities are a typical example of the abilities that most engineering professional bodies, such as those mentioned above, list as the abilities that practicing engineers need to have. I have summarised the ability statements from the EPC as follows:

- The ability to exercise key skills in the completion of engineering-related tasks at a level implied by the benchmarks associated with the following statements. The key skills for engineering are communication, information technology, application of number, working with others, problem solving, improving own learning and performance.

- The ability to transform existing systems into conceptual models. This means the ability to:

    - Elicit and clarify a client's true needs.
    - Identify, classify, and describe engineering systems.
    - Define real target systems in terms of objective functions, performance specifications, and other constraints (that is define the problem).
    - Take account of risk, and social and environmental impacts, in the setting of constraints (including legal, and health and safety issues).

- Select, review and experiment with existing engineering systems in order to obtain a database of knowledge and understanding that will contribute to the creation of specific real target systems.
- Resolve difficulties created by imperfect and incomplete information.
- Derive conceptual models of real target systems, identifying the key parameters.

- The ability to transform conceptual models into determinable models. This means the ability to:

    - Construct determinable models over a range of complexity to suit a range of conceptual models.
    - Use mathematics and computing skills to create determinable models by deriving appropriate constitutive equations and specifying appropriate boundary conditions.
    - Use industry standard software tools and platforms to set up determinable models.
    - Recognize the value of determinable models of different complexity and the limitations of their application.

- The ability to use determinable models to obtain system specifications in terms of parametric values. This means the ability to:

    - Use mathematics and computing skills to manipulate and solve determinable models; and use data sheets in an appropriate way to supplement solutions.
    - Use industry standard software platforms and tools to solve determinable models.
    - Carry out a parametric sensitivity analysis.
    - Critically assess results and, if inadequate or invalid, improve the knowledge database by further reference to existing systems and the performance of determinable models.

- The ability to select optimum specifications and create physical models. This means the ability to:

    - Use objective functions and constraints to identify optimum specifications.
    - Plan physical modelling studies, based on determinable modelling, in order to produce critical information.
    - Test and collate results, feeding these back into determinable models.

- The ability to apply the results from physical models to create real target systems. This means the ability to:

    - Write sufficiently detailed specifications of real target systems, including risk assessments and impact statements.
    - Select production methods and write method statements.
    - Implement production and deliver products fit for purpose, in a timely and efficient manner.
    - Operate within the relevant legislative frameworks.

- The ability to critically review real target systems and personal performance. This means the ability to:

    - Test and evaluate real systems in service against specifications and client needs.
    - Recognize and make critical judgements about related environmental, social, ethical, and professional issues.
    - Identify professional, technical, and personal development needs; and undertake appropriate training and independent research.

In order to develop the above list the Engineering Council, the Engineering Employers' Federation, the Engineering and Marine Trades Association, the Department for Education and Employment, the Department of Trade and Industry, and the Quality Assurance Agency were all consulted (EPC, 2002).

As a further example of the capabilities that engineers should have Bowden, also in Baillie & Moore (2004) stated that '… university students are always learning through interaction with current knowledge so as to become capable, some years in the future, of dealing with situations in professional, personal, or social contexts that can't be specified in advance. In essence, […] university students are engaged in learning for an unknown future …' (p 37). Further, he noted that engineering capability is the ability to do the following:

- Work out what the key aspects to be dealt with in each new situation are.
- Relate those aspects to the knowledge already acquired and to knowledge the engineer knows how to access.
- Determine what the underlying task or problem in a situation might be.
- Design a process or solution to deal with the situation.
- To have the ability to follow through and complete the task or solve the problem, either alone or with others.

In addition, Bowden believes that academics want student engineers to have the following skills: communication skills, problem solving skills, analytical skills, teamwork, flexibility, independent judgement, and enquiry based skills. That is they want the following:

- a knowledge of core facts,
- a general knowledge,
- an understanding of the knowledge structure in related fields,
- students to understand the theory-practice relation,
- an appreciation of real-world variation from theory,
- an ability to solve problems,
- an ability to define problems,
- lateral thinking,
- communication skills,
- insight,
- perspective,

- self-motivation,
- capacity for self-learning,
- a good appreciation of professional ethics.

In a study carried out by Harvey (1993) both academics and those who recruit their graduate engineers rated communication, problem-solving and analytical skills as the top three criteria. In addition, employers added teamwork and flexibility next while academics added independent judgement and enquiry-based skills. Knowledge per se was rated much lower by both groups and, while core knowledge in particular was considered somewhat important, there was little interest among employers in differentiating between graduates according to their specific knowledge.

Bowden (2004) argues that learning knowledge is a means to developing engineering capabilities and not an end in itself; which is consistent with Harvey's findings. Bowden continues by stating that designing a curriculum is not simply adding some new 'generic bits' to the syllabus but involves the integration of knowledge with generic capabilities.

In Bowden's view engineering capabilities have various levels as follows.

- *The scoping level:* at this level the detailed range of the capability is defined.
- *The enabling level:* at this level the specific skills related to the capability are developed.
- *The training level:* at this level the meaning of the capability in a particular field is elaborated, for example problem solving in an engineering environment is defined
- *The relating level:* at this level an understanding of the relation between meaning and context is defined. This level deals with adapting behaviour to a particular context.

Based on the above it is clear that in order to implement a curriculum based on engineers' required capabilities the overall focus is on graduates' ability to use what they know to do professional things rather than on merely accumulating knowledge. To design such a curriculum, one needs to determine the programme goals first (the intended capability outcomes), then the course goals, then the necessary learning experiences, and finally the teaching plans.

Bowden (2004) notes that for engineers to acquire the above capabilities assessment is essential but not just at the course level. Because the above outcomes are at the programme level there needs to be assessment across courses, that is, at the programme level. This in turn implies that for programme capability goals to be achieved, students need to have learning experiences in which they get a chance to integrate across various disciplines. Therefore integration and cooperation across courses is necessary. Thus there is a need for students to have varied experiences and to be encouraged to reflect on these experiences in context so that principles and contextual elements are differentiated. This then enhances the capacity of the students to apply the principles to new contexts in the future.

Finally, Bowden concludes that with capability goals, it is the students' responsibility to learn. All that educators can do is to design the learning environment so that students can develop their capabilities and to support them as they do so. In order to do this the curriculum designers must ensure that there are explicit programme and course descriptions, clear goals in terms of knowledge capabilities that explicitly integrate generic or key skills, coherence across the curriculum, supportive educators, and assessments carefully and comprehensively designed.

In order for students to take responsibility for their learning Endean and Baume (2004) note that in order to learn all students need a sense of direction; that is they need goals. They need to know where a particular course will take them and what they will be able to do at the end of it. In summary, clear statements of the aims and the intended learning outcomes of the course are necessary. This means that not only does a curriculum designer have to decide the aims and learning outcomes for a course but also has to communicate them to the students. Endean and Baume conclude by remarking that in order to learn, students also need, in addition to a sense of direction and a set of goals, appropriate learning activities. So a curriculum designer must be aware of the types of student learning activities that will help them to become able to attain the course outcomes.

Mathematics is an important aspect of engineering education so to conclude this introduction to modern curriculum design it is worthwhile to consider the work of Hirst, Williamson, and Bishop (2004). They quote the Royal Society on mathematics and science education as follows: ‘Fluency and confidence in the knowledge and use of mathematics and science comes with repetition and practice but deeper understanding comes with experience of transferring concepts and principles to new contexts and applications’ (The Royal Society, 1998, p. 101). Hirst, et al. continues by stating that engineering students need a broad base of mathematical knowledge that they can apply to engineering processes. They use Malpas’s (2000) definitions to define knowledge and process in engineering as follows:

- ‘Knowledge is the growing body of facts, experience, and skills in science, engineering, and technology disciplines; coupled to an understanding of the fields of application.’
- ‘Process is the creative process, which applies knowledge and experience to seek one or more technical solutions to meet a requirement, solve a problem, and then exercise informed judgement to implement the one that best meets constraints’ (p. 102).

However, Hirst, et al. note that students beginning engineering courses often have a wide range of mathematical knowledge. Therefore, in order to overcome this problem they suggest using diagnostic testing to determine the students’ level of mathematics and to better target curriculum design. They believe that diagnostic tests for mathematics can identify specific weaknesses in students’ mathematical knowledge; however the following need to be noted:

- Academics need to advise students of the diagnostic test and supply revision materials before arrival.

- The purpose of the diagnostic test must be clearly defined, that is it is not part of the formal assessment.
- There must be follow-up and support for the students.

4.3.2 Curriculum Design Philosophies

According to Toohey (2002), the curriculum design philosophies in higher education fall into the following five categories: traditional or discipline based design, performance or systems based design, cognitive based design, personal relevance or experiential based design, and those based on a critical analysis of society. Obviously, many actual curricula are designed using a combination of these philosophies. The following sections investigate the major characteristics of each of these philosophies. The following is my brief summary of Toohey's excellent book Designing Courses for Higher Education (Toohey, 2002). In her book Toohey gives many examples and case studies to support her statements which I have omitted in order to keep my summary to a reasonable length.

My summary of Toohey's work comprises sections 4.3.2.1 to 4.3.3.3 apart from short sections from other authors which are separately referenced.

4.3.2.1 The Traditional or Discipline-based Approach

Most tertiary course design has traditionally followed the structure of the knowledge in the discipline. Programmes of study are divided into units based around the important concepts and each topic is logically structured. For example, in Euclidean geometry the theorems are arranged from the most simple to the most complex. That is, a logical basis is used to structure the course; whether it is chronological, causal, based on the scale of operation, or on the form of expression; it exists within the subject matter itself and the way in which the discipline is commonly ordered. Importantly, it is not related to the students' interests, the way students learn, or the ways in which problems present themselves in daily life.

In this view of the curriculum, knowledge is believed to exist independently of cultural and social structures. It exists in published records and forms a body of theory which has been developed, refined, and tested over time. These records are then accessed by students as required. Usually the emphasis is placed on the technical, rational, and managerial aspects of knowledge which help to give greater control over the world rather than on personal or expressive knowledge. This view of knowledge tends to be biased towards the abstract and theoretical.

The role of the educator is to sift through this knowledge; which consists largely of information, facts, and concepts; and select what is important for students to know and to *transmit* that to them. Educators may also provide exercises for the students which are designed to confirm what is known or to give them practice in the mode of inquiry related to the particular discipline. In this perspective on knowledge students are assumed to be motivated and prepared to learn, diligent in carrying out their assigned tasks and in memorizing important information.

In curricula designed using this philosophy students are expected to acquire a broad knowledge of the discipline, its key concepts, and the methods of inquiry used within the discipline. Curriculum objectives are usually lists of important topics with which the student must become familiar.

The content in the curriculum is chosen for breadth so that students get a representative picture of the field and is logically structured and sequenced according to the nature of the discipline. It is considered important for the curriculum to 'cover' the discipline with the result that the opportunity for thorough investigation into any particular topic is not feasible.

Assessment in this form of curriculum is used to confirm the extent of knowledge and to rank students. The main types of assessment are usually paper-and-pencil tests, ranging from multiple-choice and short answers to long essays and they are usually marked on a finely discriminating scale. Traditionally the assessment results were norm referenced.

Education based on this type of curriculum can be economically delivered to large classes which means that it is an efficient use of the educator's time because it allows one person can lecture to large numbers of students. Tutorial work, laboratory classes, and marking are usually assigned to teaching assistants because the exercises are specified in advance and the outcomes are clearly defined. Under this model textbooks and printed lecture notes adequately summarise the important knowledge and reduce the demand on libraries and primary sources.

4.3.2.2 The Performance or Systems-based Approach to Curriculum Design

This approach is adopted by educators who do not view course design as a problem of values or philosophy but as a technical problem. That is, they see it as being a question of what means are required to achieve desirable results and of how these results may be measured so that improvements can be scientifically based. Educational technologists believed that by introducing a 'systems approach' to course design they would be able to bring the methods of applied science to education. This approach to curriculum design was developed from the work of Ralph Tyler (1949). He stressed that education should be a purposeful activity and that institution of learning needed to define their objectives. The institutions should then teach with these objectives in mind and assess students' progress to see whether the goals are being achieved.

In order to implement this scientific approach to curriculum design Tyler proposed the following four questions for curriculum developers:

- What educational purposes should the institution aim to attain?
- What educational experiences can be provided that would be likely to attain these purposes?
- How can these experiences be effectively organized?
- How can we determine whether these purposes are being attained?

The work of Tyler was developed and became the ‘instructional systems’ approach to course design (see, for example, Taba, 1962; Wheeler, 1967; Kemp, 1977; Nicholls and Nicholls, 1978). One of the chief proponents of this method, Romiszowski (1984), defined an instructional systems approach as follows:

> It is the presence of precise goals or objectives (however they are arrived at) and the presence of careful pre-planning and testing that are the main characteristics of our use of the term ‘instructional system’. Instructional systems design is therefore a three-phase process of establishing precise and useful objectives, planning study methods, and testing them (p. 51).

In the instructional systems approach, again following the work of Toohey (2002), learning objectives must be clearly defined in advance and specified in behavioural terms so that it is possible to accurately determine if they are being met. If the programme is successful, that is if the objectives are being met, it can then be replicated. This means that the advantages of a well-planned and carefully evaluated education can be brought to large groups of students who are not fortunate to have talented and creative educators. A well-designed curriculum is therefore seen as a quality control mechanism which can compensate for substandard teaching. This approach to curriculum design has been particularly attractive to governments because it holds out the promise of accountability.

The view of knowledge and learning that the proponents of a systems approach adopt is that the only evidence that one has that knowledge and understanding have been achieved is determined by the performance that a student is capable of. That is, evidence of students’ understanding is shown by what they are able to do and the purpose of learning is to expand the students’ repertoire of skills and ways of behaving. Therefore knowledge is useful only if it informs action, and there is no dichotomy between theoretical and applied knowledge as there can be in discipline-based programmes. In fact, in this approach, theory is taught only if it can be applied.

Key to this approach is the idea that learning takes place effectively when learning tasks are broken down into their component knowledge and skills. These tasks are then structured and sequenced so that new learning builds upon prior learning until complex performances can be mastered. The role of the educators varies considerably depending on whether they are the designers of the course or whether they are merely facilitating the course. When educators are course designers they have a complex role. They have to determine the performance outcomes of the course, analyse those performances to determine what kinds of skills and knowledge are required, determine the sequence in which they should be introduced, plan the appropriate learning tasks, and schedule frequent assessments so as to provide feedback on the students' progress and to identify the need for remedial action.

If the educator is not the course designer - for example when a course is being delivered largely through computer-assisted instruction or other educational media, the educator's role may be limited to facilitating group work, assisting students, responding to questions, and giving feedback on assessments.

In this approach to curriculum design the students have a simple role; that is they follow the learning steps that have been set out for them. The systems approach allows little choice for students in terms of what they will learn because the core skills have been determined through research into the nature of practice. However, if self-instructional materials are used, courses designed in this way can often allow flexibility in timing. An advantage of this approach is that expectations are clearer and clear objectives with regular feedback on performance can increase the students' confidence and sense of achievement.

In this view of the curriculum the learning goal is to become a skilled performer and is often seen as particularly appropriate for designers of engineering and other professional programmes. In this approach objectives are specified in terms of behaviour and are often laid out for students in a learning hierarchy which shows how the course objectives build upon each other and how they contribute to the final skilled performance.

An important point to realise in the systems approach to curriculum design is that content is not chosen according to educator or student interests but based on research into the nature of practice in the particular profession. This research aims to identify the skills which are used, the kinds of knowledge required, and the factors which are important for effective performance. This knowledge is then used to design structured learning experiences, involving practice and feedback, which should ultimately lead to the required performance.

In this approach assessments are frequent in order to provide feedback to both the educator and to the students. Failure on an assessment, which is usually criterion-referenced, indicates a need for remedial action before further progress can be made. Final assessments are designed to certify that the required level of competence has been attained. Assessments may be marked on a satisfactory/not-yet-satisfactory basis or at lower levels may be graded for higher levels of performance.

Curricula designed using the systems approach are often easily adapted to delivery through a range of educational media and therefore via distance education. However, instructors trained in the development of interactive multimedia, computer-based instruction, or educational videos are usually needed to develop these courses. In addition to using media like video to demonstrate aspects of performance, performance-based programmes need access to a range of equipment, materials and specialized work spaces, like laboratories, in which students can practise the required skills.

The systems approach emphasises the performance of measurable skills and can therefore ignore values or give the impression that values are not important. That is, this approach makes no place in the curriculum for examining the ethical issues that are involved in the way, for example, a profession interacts with society or how the individual practitioner interacts with clients.

4.3.2.3 The Cognitive Approach

In this view the major functions of a tertiary institution are to develop the students' minds, to help students to learn how to learn, and to provide them with opportunities to use and strengthen their intellectual faculties.

The idea of a course of study to promote cognitive development has existed in various forms since the time of Plato (see section 4.2.1.2 above). In this view it is theorised that some subjects are important not for their content but because they developed specific faculties. For example mathematics was thought to develop logical thinking. That is, it was assumed that the kind of logical thinking developed in mathematics would transfer easily to other areas of knowledge. Thorndike (1913) tested this assumption and he concluded that students could transfer what they had learned in one situation only to similar situations, that is general transfer across domains of knowledge did not occur.

The concept of faculty transfer was revived by recent psychological research on the structure of the intellect. This has resulted in the dominant approach within educational psychology moving from behaviourism to cognitivism with the focus of research moving from reproductive learning and memory to thinking, reasoning, understanding, and the making of meaning. Posner (1995) described this as follows:

> Cognitive views derive directly from the ideas of the philosopher Immanuel Kant, who claimed that people may be born with certain capacities or 'structures' for acquiring language, concepts and skills. These innate structures develop as the individual develops. Furthermore, knowledge and beliefs the individuals acquire affect the way they perceive and think about subsequent ideas, objects and events. Thus people do not passively receive information from their senses; rather they actively construct ideas and generate meaning from sensory input by interpreting the input on the basis of existing ideas and previous experience (p. 107).

Hence the move to cognitivism among educational psychologists resulted in the curriculum being seen as a vehicle for assisting students to develop intellectual abilities, although the current focus is on acquiring the conceptual structures and thinking processes of a particular discipline. Resnick (quoted in Posner, 1995) highlighted the importance of both in the cognitive curriculum when he stated that:

> … to understand something is to know relationships. Human knowledge is stored in clusters and organised into schemata that people use both to interpret familiar situations and to reason about new ones. Bits of information isolated from these structures are forgotten or become inaccessible to memory.
>
> Good thinkers and problem solvers differ from poorer ones, not so much in the particular skills they posses as in their tendency to use them … the habit or disposition to use the skills and strategies, and the knowledge of when they apply need to be developed as well (p. 108).

Continuing with the summary of Toohey's book - she notes that cognitivists view knowledge is personally constructed although this does not mean that one person's views are as good as another's. Some explanations are superior because they are based on stronger evidence and withstand rigorous examination. Where the material to be learned is complex and does not correspond with previous experience then poor understanding and misconceptions are possible, that is misunderstanding becomes likely. In general the conceptual structures of experts are used as a guide because they are richer and more useful than those of novices. To summarise, the habits of rigorous thinking and analysis are not innate but need to be cultivated and developed.

An important aspect of the cognitive approach is the realisation that the continual refinement of ideas and intellectual abilities, and the development of a well-structured knowledge base, implies that the educator and students work through a limited amount of material in considerable depth. In order to do this class work is focused on real-world examples and problems to ensure that the students integrate their new knowledge with previous experience. It is the educator's responsibility to be aware of areas where misunderstanding could occur, to bring the students' misconceptions to light, and to challenge them to come up with improved explanations that correspond with all the evidence. Therefore small-group work is a necessity because students need to critically examine their understanding and beliefs. Critical examination is difficult to undertake alone and therefore the key to the cognitivist approach is to constantly facilitate the process for the students. The educator's questioning skills are important because the types of questions raised by the educator should lead the students to levels of analysis which they would not have attained alone.

In the cognitive approach the development of the thinking process is the objective. This contrasts with the systems view in which the educational goal is an increasing repertoire of skilled performances by the students. The aim of the cognitivist view is high-quality thinking evidenced by rigorous analysis and argument, good problem identification, and good problem solving. Therefore thinking is both the purpose and the content of the curriculum. Learning goals are typically expressed as follows: 'students will learn to think critically, become lifelong learners, and be able to solve problems'. A difficulty of this approach is that these types of objectives are to do with changes in the students which are not immediately apparent. This means that assessments have to be formulated as performance tasks through which students can show their increased intellectual capacities.

The content in the cognitive curriculum is not chosen for a wide coverage of the topic but in order to master important concepts and practise intellectual abilities. Resnick and Klopfer (quoted in Posner, 1995) noted that a cognitively based curriculum eliminates the competition between content and skills because 'concepts are continually at work in contexts of reasoning and problem solving … there is no choice to be made between a content emphasis and a thinking-skills emphasis. No depth in either is possible without the other' (p. 113). Traditionally, as Toohey notes, because degree programs are limited in time, there is a bias towards breadth of analysis rather than depth. Therefore in the cognitivist approach to curriculum design the content may have to be pared back in order to emphasize cognitive development.

Toohey continues that in cognitively focused curricula assessments must enable students to show the complex understandings and increased intellectual abilities that they have developed. Therefore assessment tasks involve complex problems that require students to consider context in their response. This results in assessment tasks that are not easily evaluated and require judgement on the part of the assessor. Nevertheless, using the cognitivist approach, students will expect assessors to articulate the evidence on which they made their judgements and to defend their decisions. Since the learning aims of cognitivist curricula emphasize ill-defined abilities such as critical thinking or problem solving; it is important for students that the assessment criteria are clearly articulated so that they understand what it means to be a critical thinker or a problem solver in the field being studied. In addition, due to the emphasis on acquiring evaluative skills, cognitive programmes are likely to include students in the assessment process via self- and peer-assessment.

Cognitive programmes require a high degree of interactive small-group work with guidance and challenges from an expert group leader because students need opportunities to engage in active questioning of ideas and to practise thinking skills. Although students may be able to organize themselves effectively to undertake many learning tasks it is difficult for them to challenge their own thinking. Therefore the resources needed for cognitivist programmes are adequate student-educator ratios for small-group work and appropriate accommodation. These resources must be combined with libraries and collections of other resources to support the level of independent investigation required.

Although open learning and distance education programmes are becoming popular with governments and higher education managers it is not easy to implement cognitivist programs via distance learning. This is because it is difficult to provide, at a distance, the opportunity for extended interaction with others that promotes the deep processing of ideas and the development of intellectual abilities that the cognitivist approach requires.

4.3.2.4 Experiential or Personal Relevance Approach

Malcolm Knowles (1984) put forward the idea that adult students need a different kind of educational approach from children. He believed in the importance of personal relevance and in learning from experience. This belief implies that educators design educational programmes in conjunction with the students in order to meet their individual needs and interests. A basic tenet of his andragogical model is that

> [a]dults do not learn for the sake of learning; they learn in order to be able to perform a task, solve a problem, or live in a more satisfying way. The chief implication of this assumption is the importance of organising learning experiences (the curriculum) around life situations rather than according to subject matter units (p. 12).

Knowles's approach contrasts with traditional programmes in which the structure of the course is imposed on the student and the educator determines the sequence of learning and what should be learnt. In the experiential approach the students nominate, within limits, the skills and knowledge that they want to acquire and the kinds of problems with which they want to be able to deal. The student's previous life experiences and those experiences which can be planned and organized as part of the course are valued highly by this approach.

4.3.2.5 The Socially Critical Approach

This approach aims to develop the students' critical abilities so that they develop an awareness of the ills of society and become motivated to alleviate them. A socially critical view of the curriculum draws upon the work of theorists who believe that the institutions of society are created and moulded by various elite groups. They believe that the role of those institutions, including educational institutions, is to maintain and support the influence of these elite groups. For example, social critics believe it is not accidental that the children of disadvantaged groups are not equitably represented in higher education. They believe it is because the system is designed by and for the socially advantaged. A socially critical curriculum is, therefore, designed to examine society, its institutions, its cultural products, and to expose the hidden values that guide the way institutions work. Unsurprisingly this approach has been influential in the humanities and social sciences; however critical theorists have also begun to influence the applied sciences where they have questioned the usefulness and appropriateness of some technologically based solutions to social problems.

Social critics view knowledge as constructed within historical and cultural frameworks; that is, knowledge is historically, socially, economically, and politically influenced. They believe that one creates understanding through interactions with people who tend to be of a similar background, culture, and social class as oneself. In addition, they believe that people who are socially and economically powerful are likely to have their views taken into consideration when policy is formed or curricula are developed.

The socially critical perspective sees learning in a similar way to the conceptual change model proposed by the cognitivists. That is, the students and the educator work together to understand and critique social institutions or work on collaborative projects which have social significance. The educator's role is to help students understand the origins of their own views and to challenge preconceptions in order to encourage them to consider alternate possibilities. The key aim of a socially critical curriculum is the get the students to ask, 'Whose interests are being served here?' That is, students must be able to develop arguments and to defend their position; but more importantly they must be capable of self-realisation in a social context and not purely as individuals.

It is not immediately obvious how this approach could be applied to engineering. One option is to use this method to consider the uses to which engineering research is put, to analyse the influence of engineering on the environment, and to examine the social impact of technology and engineering solutions. The content of the curriculum could then be organised around themes and be implemented via investigations or projects.

Assessment in the socially critical curriculum, as was done with the experiential approach, consists of negotiation between the students and the educators about the kinds of evidence of learning that will be accepted for successful performance. Collaborative work and group projects, and self and peer assessments are often used.

The aim of the assessment plan is to aid students to develop the skills of critical inquiry, independent judgement, and the ability to work in groups. Because the socially critical curriculum requires interactive small-group work and because the projects and investigations in the curriculum are often community based, this type of approach to the curriculum can be expensive to run.

Although the systems approach to the curriculum and the socially critical approach are different in many ways they both look beyond exigencies of the discipline or the interests of the individual to society for their educational goals. The systems approach determines which skills are important for society. The socially critical approach asks what kinds of knowledge and skills, other than those currently accepted, may be valuable to society. Both the systems and socially critical approaches view knowledge translated into action as important. The systems approach values skilled performance and the socially critical approach values social action.

In reality most education institutions support aspects of all the above approaches to the curriculum however they are limited by time and financial constraints. Therefore the predominant model in most institutions is the discipline approach with its emphasis on breadth rather than depth. Governments tend to favour a competency based approach because it has the potential to increase accountability. They have, therefore, attempted to influence universities and colleges to adopt it, for example in vocational education in Australia, the UK, and NZ. They are able to do this because vocational education is under direct government control. For similar reasons many professional bodies have also endorsed the competency based approach.

4.3.3 Designing a Curriculum

Various techniques may be adopted in order to aid the design of curricula. As mentioned above, under the discipline based approach, one way to determine the skills that a particular course must inculcate in a student is to examine the skills that a master performer has in that discipline and try to structure the course to develop those skills. This is often the approach adopted by professional bodies. Other useful techniques are to draw a concept map of the course or to set up a conference among the relevant people involved in the course to see which macro and which micro influences impinge on the new program. In addition, professional bodies, employers, and professional practitioners can help to define a course's content. Finally, a functional analysis of professional skills, text books, and academic staff can highlight current practice and which core material is important (Toohey, 2002). It is interesting to note that, from surveys of students, Diamond (1989, p. 89) found that '[i]t became apparent that a common base of meaning and definitions had to be developed before [a] course could be effectively taught', as was discussed by Plato in section 4.2.1.1 above.

4.3.3.1 The Structure of the Course

Within each curriculum philosophy, described in section 4.3.2 above, the subject matter, according to Toohey, may be arranged in various ways. This section summarises these ways. It should be noted that each of these ways of organising material is not necessarily relevant to each curriculum philosophy.

A Logical Structure

In this structure the content is arranged according to the organization of the subject matter. This method follows the way knowledge is structured in the discipline but often does not suit the needs and interests of the students.

A Competency-based Structure

In this method the performances for which the students are being educated are identified and a course is built around these performances. Once the performances have been identified they are analysed to determine what knowledge, skills, attributes and dispositions students will need to acquire in order to perform them.

Once identified, the knowledge and skills are then ordered from the elementary, prerequisite ones to the more complex, sophisticated ones. As Gagne (1977) notes, this method results in a psychological rather than a logical structure of knowledge and the identifying and teaching of prerequisite skills is emphasised. Toohey adds that an advantage of this method is that is may identify skills which may not be highlighted in the logical approach.

She continues that the competency-based structures are popular with governments because the students who pass the course should be competent to practice. Courses designed in this way are perceived to be more relevant to the economy and be more flexible because prior learning can be recognised. This simplifies the movement of students between different levels of courses and between courses.

Continuing with the summary of Toohey's book she comments that the competency-based programs have a number of advantages. For example, the students are motivated because they understand the structure of the course and see its workplace relevance, the material is structured so that students are less likely to encounter steps beyond their capabilities, and skills which are not normally covered are taught in this approach. A disadvantage of these programs is that they do not cater for students' individual interests, that is, they are not flexible. In addition, in a competency-based course the trade-off for a better understanding of the professional role may be a weaker discipline base which can be detrimental for students going into research or academia. Finally, a more serious criticism may be that, because this approach has a strong identification with a profession, there may be little or no opportunity within the course to critique and evaluate the professional role as it is currently conceived.

A Problem-based Structure

Most modern programs include projects and problems however these are used to learn to apply knowledge gained from lectures, tutorials, and textbooks. Programs based entirely on problems (projects) use problems or situations to stimulate students to discover and explore the key concepts and skills of the discipline. They do not use problems merely as an opportunity to apply the knowledge gained through lectures, etc. From the beginning of the course students are presented with problems that they may encounter in professional practice.

Typically, in this approach, by working in small groups with a facilitator, the students analyse the problem and highlight those aspects about which they need to know more before they can progress towards a solution. These aspects become the subject of independent or group study and may be approached through resource materials, lectures provided by academic staff or people in the community. Once the initial learning needs have been met, the group reconvenes with its facilitator to address the next stage of the problem. Although problems are eventually ‘solved’ by the students and the facilitator agreeing that a particular course of action is the best available from the range of possibilities, the aim of the course is not to find solutions. The aim is to use the problem to decide what one needs to learn.

A difficulty with this method of arranging study material is that the problems must be carefully chosen so that students continually extend their knowledge and skill, building on what they have learned with previous projects. The projects selected must be designed so that they enable all the essential concepts and skills to be addressed. However, because project based courses are designed to promote experiential learning they should develop a wide range of knowledge and skills in the students. A disadvantage of this structure, particularly for novice students, is that it may not develop a structured knowledge base. Therefore developers of problem-based courses need to select and develop the projects for the students within a clearly structured framework that will help them continuously develop their abilities.

Project based courses are claimed to develop a students ability to solve problems, develop their skills in self-directed learning, self evaluation, and group work. Albanese and Mitchell’s (1993) meta-analysis of studies comparing medical students on project-based learning (PBL) courses with those on more traditional courses found that the students on project-based courses scored lower on basic science but scored better on clinical performance. PBL students tended to emphasise study methods which developed understanding rather than rote learning and tended to enjoy their courses more. PBL courses tend to be more motivating for students because they are perceived to be dealing with significant problems which are relevant to their future careers. In addition, PBL courses encourage the integration of theory and practice. However, PBL courses cover traditional material at a slower pace and it is difficult for novice students to extract general principles from particular tasks or problems.

Toohey notes that another disadvantage of project based programs is that some staff members have difficulty adjusting to PBL because they have to move from being experts and authority figures who provide information to being group facilitators who let students make decisions and intervene only when asked questions and when needed to redirect inquiries. In addition, the facilitators are required to feel comfortable in areas in which they are not expert, they must develop good questioning skills, they need to develop the ability to work within a group, and they must learn to help students resolve conflicts. Furthermore, the development of PBL courses and good course material takes an inordinate amount of work on the part of the educators.

A Cognitive Structure based on Key Concepts or Intellectual Abilities

Another possibility for structuring curricula is to organise the course content and activities around key concepts, for example, power generation in electrical engineering. This approach is based on the idea that concepts form the substantive structure of a discipline; that is they are the fundamental ideas which subsume more specific facts. Alternatively, a course could be structured around concepts and abilities which are not specific to a particular discipline such as critical thinking or reflective practice. The content and learning activities are then chosen so that they present many opportunities to practise and refine these key abilities.

The advantage of this structure is that the most important ideas of the discipline and important modes of thinking are practised and established, and fundamental misconceptions and weaknesses in thinking are likely to be exposed. This course structure accords with many educationalists who regard the mastering of significant ideas and habits of thinking as the most important outcome of a tertiary education.

Again a disadvantage of this structure is that the students do not get as well structured a ‘map’ of the knowledge in a discipline as in a discipline based course. In addition, the students may not get as good an idea of how concepts in a discipline originated. Another disadvantage is that the material used to explore the key concepts may not be directly relevant to the students’ interests and so may not be optimally motivating for the students. As with PBL courses, group work is required which in turn requires the facilitators to feel comfortable in areas in which they are not expert, they need to develop good questioning skills, they need to develop the ability to work within a group, and must be able to help students to resolve conflicts.

Hybrid Structures

Most modern courses are hybrid structures of two or more of the above approaches. However, for these hybrid structures to be beneficial to the students they must be thoroughly planned and must not just evolve randomly.

4.3.3.2 General Comments on Syllabus Design

Toohey notes that a number of authors have recommended a tertiary education which would provide technical skills first and then a general education later. This approach has received the support of students because it fits with the way learning develops in many people. Students under the age of thirty have a strong motivation to acquire skills which will make them employable, useful, respected, and help them to establish themselves as independent adults. In addition, this age group find it difficult to critically appraise their profession.

It is generally accepted that current tertiary education courses are designed to develop specialist knowledge of a particular discipline. This includes ways of thinking and problem solving which characterise the discipline as well as the acquisition of extensive detailed factual knowledge. It is not difficult to achieve the factual knowledge part of a tertiary education because, as Bligh (1975) pointed out, text and lectures are efficient means for transmitting information. In fact he showed that text is as efficient as lectures in transmitting information.

However, Toohey comments that conceptual change and intellectual development, such as critical inquiry, building and defending an argument, and understanding concepts which run contrary to everyday experience, is far more difficult to achieve. In order to achieve these cognitive outcomes small group study is usually necessary. In small groups students can work on problems with others, discuss their results with the group, and make adjustments to their conceptual understandings. Discussions allow the highlighting of misunderstandings, the analysis of the effect of different variables, and the exploration of different approaches.

The levels of learning mentioned in the above two paragraphs have been clearly summarised by Säljö (1979) and have proved useful as a structure for thinking about curriculum design. The levels of learning form a hierarchy in which the later levels incorporate the earlier ones. The levels are:

- Reproductive learning:
    - Learning as acquiring knowledge.
    - Learning as memorising and the long term retention of facts.
    - Learning as application, in particular, algorithmic application.

- Personal understanding:
    - Learning as insight or understanding; that is the ability to use one's knowledge to interpret and understand new material.
    - Learning as personal development, that is the ability to problem solve and to develop a personal philosophy.

Marton, Beaty, and Dall'Alba (1993) added learning as the key to changing and developing as a person to the above list.

Toohey adds that educators want their students to be able to do the high level learning outcomes, mentioned above, which enable students to critically analyse, to solve complex problems, and build logical arguments based on evidence. They also want them to know when and how to use the tools and techniques of their profession. However, in reality, it is the course assessment that usually indicates to students what type of learning is required in a particular topic rather than the curriculum specification.

4.3.3.3 The Effects of Syllabus Design on Teaching, Learning, and Assessment

The Influence of Curriculum Design on Teaching and Learning

Continuing the summary of Toohey's book, the approach used to design a syllabus will influence the teaching, learning, and assessment carried out in a particular course. Only one component of a teaching strategy is directly about the activities of the educators. A teaching strategy is actually a plan for someone else's learning. It therefore encompasses the presentations which the educator might make, the exercises and activities designed for students, the materials which will be supplied or suggested for students to work with, and the ways in which evidence of their growing understanding and capability will be collected. A modern teaching strategy may not include the kind of activity that we commonly think of as teaching; that is an educator formally addressing a group of students.

Many factors other than their approach to learning affect the achievement of learning outcomes for students. Biggs (1987) found that these factors include the student's prior knowledge, their IQ, their personality, their background and motivation; as well as aspects of the educational context such as the nature of the subject, the course structure, the teaching strategy, the time available for the learning task and the nature of the assessment.

As Toohey notes, because all of the above factors affect learning outcomes to some degree it is not possible to specify that a certain strategy is optimum for achieving a specific learning objective. Researchers into teaching and learning strategies are careful to note that the strategy which worked for a particular group of students on a particular concept or skill, in a particular context, may not necessarily translate effectively to other students, other topics, other contexts. These investigations can suggest strategies which would seem to have a chance of success, but they cannot prescribe with any degree of certainty. Selecting a teaching strategy for a particular topic to be used for a particular group of students is an art not a science. Because it is not helpful to advise new course designers that planning teaching strategies is an art which is refined and developed through long experience it is necessary to know what kinds of understandings or principles can guide a curriculum designer .

Toohey suggests the following simple model of the learning process (I have redrawn Toohey's diagram in a simplified form):

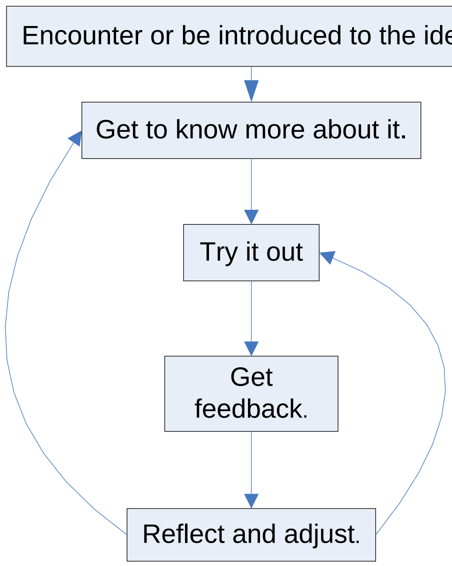

Figure 4.1 Toohey's Learning Process

She then notes that the traditional methods of teaching used in tertiary institutions are capable of supporting all of the above stages of learning. That is, lectures and readings can be used to introduce students to new material and provide them with significant amounts of information and a range of different views which covers the first two blocks above, that is *being introduced and getting to know more about a* *topic*. Laboratory work, tutorials, small-group work, and assignments can give students the opportunity to *try out their new knowledge, get feedback, and to reflect and try again*. However, she notes that frequently:

- The balance between these methods is incorrect with too much emphasis placed on the first two stages. Many courses have twice as much time scheduled for lectures as for practical or group work, and small-group sessions are often limited due to budgetary pressure.
- There is usually little attempt in the first two stages to find out the students prior knowledge or to determine their misconceptions.
- Often the teaching activities don't occur in the optimum sequence. Lectures and tutorials may be out of synchronisation so that the practical work and discussion topics are not related to the lecture material.
- Educators may lack the skills in planning and facilitating group work which is necessary to get students to participate. This results in small-group sessions being converted into mini-lectures.
- In many tertiary institutions the opportunities for feedback and quality of feedback are inadequate because classes are overcrowded and the educators have excessive marking schedules.

Understanding and mindfulness on the part of students can be enhanced by the kinds of teaching and assessment strategies which are chosen. If the educators adopt a strategy of probing and challenging which requires the students to relate new material to the knowledge which they already possess, if they ask students to teach others, and if the students work in teams, then mindful learning and the consequent transfer of learning to new situations appears to increase.

An additional factor which Salmon and Globerson (1987) have found to be significant for developing transferable learning is for the students to have many opportunities to practise new skills and knowledge. In summary, mindful reflection allows students to analyse the adaptations which must be made for different contexts and practice consolidates the key elements of the learning. As mentioned in section 4.2.1.2 above it is not automatic that cognitive ability from one sphere of learning will be transferred to another. However, Toohey notes that the research which has been done on transfer of learning indicates that it is important that students are given many opportunities to develop academic and generic skills in a variety of contexts and to encourage their awareness of what it is they are doing.

The Influence of Curriculum Design on Assessment

Continuing with Toohey, curriculum designers need to be aware that different assessment techniques need to be used to satisfy as far as possible the many expectations of assessment in tertiary education. In addition, as always with curriculum issues, one needs a strong awareness of one's objectives and the requirements of other users of the system. Usually it is not possible to meet all these objectives and requirements completely.

Traditionally norm-referenced or criterion-referenced methods of assessment have been used in tertiary institutions. These two methods are usually regarded as being distinctly different approaches. However, as Toohey has pointed out, norm-referenced and criterion-referenced systems are not as distinct as their advocates believe; the standards in a criterion-referenced system are usually derived from some idea of the norms for performance at a given level of a course. However, these two systems do have some significant differences. Criterion-referenced systems have their assessment criterion made explicit and have few grading levels whereas norm-referenced systems have many grades and the marks are adjusted to follow a normal distribution. Therefore the assessment criterion need not be as explicitly defined in a norm-referenced system.

As mentioned above, Habermas (1972) divided knowledge into three categories and each of these different categories of knowledge imply different kinds of assessment. Technical, empirical, or conventional knowledge is distinguished by the fact that it is the object of general agreement and acceptance. Rules, formulae, vocabulary and procedures all represent codified and established knowledge. Assessment of this kind of knowledge allows little room for interpretation or individual response because there is usually a 'right answer'. Therefore objective tests, such as multiple choice, true/false, or sentence completion are suited to assessing this kind of knowledge. The students' ability to carry out standard procedures and operations can be assessed on a *can/can't do* basis by using observation and standard checklists of the steps required in the process. These assessment methods are inherently easy to mark because there is little room for disagreement between different markers and therefore reliability is high. The weighting given to technical knowledge, and the extent to which such knowledge is believed to be worth assessing separately from more complex kinds of understandings, will depend on the nature of the discipline and on what is valued by the course designers and educators.

Habermas's second and third categories of knowledge are more difficult to assess. The second category of knowledge, that is communicating with and understanding others, is more subjective and therefore difficult to assess. The third category, that is self-reflective knowledge related to freedom and autonomy, can not be assessed in any objective way because it deals with personal individual development.

In conclusion, Mentkowski, Astin, Ewell, and Moran (1991) noted that:

> '[l]ately … I've … begun to identify some of the educational assumptions that are beginning to drive higher education assessment more broadly. I can see three intertwined but distinct aspects: First, expanding the outcomes of college to include not only what students *know* but also what they are able to *do* has led to development of alternative assessments, including performance and portfolio assessment. Second, expanding learning to include active collaboration with others and more reflective and self-sustained learning, has led to assessment of projects produced by groups of students and to more attention to self assessment. Third, expanding educational goals to include personal growth has led to assessment of broad developmental patterns over time …' (p. 5).

The next and final chapter summarises chapters 1-4 and draws conclusions about the structure of the engineering syllabus.

CHAPTER 5
ANALYSIS OF THE ENGINEERING CURRICULUM

5.1 Introduction

This chapter uses the information presented in the previous four chapters to critically analyse the electrical engineering curriculum across the three types of tertiary institutions in New Zealand. Specifically, the three institutions are the Auckland University, the Auckland University of Technology (AUT University), and the Manukau Institute of Technology.

As explained in the first chapter, this analysis is both important and necessary because the success rate of tertiary students in general and engineering students in particular is not acceptable by any yardstick. For example, chapter one points out that only about 48% of all tertiary students in New Zealand complete their studies: a statistic that surely would not be acceptable in any other field of endeavour.

This chapter begins by using the information in the second chapter to define exactly what electrical engineering studies are and to point out that engineers, as in most professions, do not stop studying when they leave university but continue to study throughout their career. It then discusses teaching and learning in engineering, the existing electrical engineering curriculum, and analyses the problems with it. The next section discusses how an electrical engineering curriculum should be set up using the latest theories on teaching, learning, and curriculum design. The chapter ends by drawing some conclusions from the above analysis and by suggesting some further areas of study that need to be undertaken.

[Because this chapter is a set of summaries and conclusions drawn from other summaries, for simplicity of reading references will be quoted only if they have not been quoted in previous chapters.]

5.2 The Definition of an Engineering Education

5.2.1 Summary of General Educational Ideas

Chapter two is an important starting point for analysing engineering curricula because it puts an engineering education in perspective; it enables one to define what exactly an engineering education is - relative to current and historical ideas of education. This in turn influences the design of the engineering curriculum, the teaching of the curriculum, the type of learning that takes place, and its assessment. The second chapter also discusses the various definitions of education that have been proposed since the time of the ancient Greeks. This section will begin with a summary of the ideas in chapter two and then show how they relate to a contemporary engineering education.

The first definition that chapter two deals with is that of a *moral education*. It explains that education may be seen as a mechanism to provide students with a moral basis from which to live their lives. However this moral basis can be seen from a number of perspectives. First, it can be viewed as an education that gives one the moral positions that enable one to be of service to humanity. Second, it can be seen as an education that gives one the tools to be of service to the state. Third, it could be an education which enables one to be of service to god or the gods, and finally, according to Nietzsche, it could be seen as a mechanism through which one is taught one's cultural heritage and how to pass this heritage on to future generations.

The second overall definition of an education in chapter two is that of a *liberal education*, that is, an education that is mainly concerned with broadening a person's general knowledge and experience. Again, a liberal education can be seen from a number of perspectives. First, a liberal education can be viewed as an education that transmits established truths to students. Second, it can be seen as an education that inculcates judgement, wisdom, and foresight. Third, a view that has been promoted for centuries is that a liberal education is an education that undertakes learning for learning's sake and not for any proximate outcome. Fourth, closely related to this third view, is the idea that an education should enable one to self-learn. The fifth approach to a liberal education is that of enabling a student to gain a real self-awareness and to get to know the bounds of one's ignorance.

The next category of education defined in chapter two is that of an *education for power*. The first sub-category under this heading is that of an education for financial gain. The second sub-category is from the other end of the economic spectrum, namely, an education that cures alienation: particularly in the sense used by Marx. The third form that an education for power takes is that of learning how to do things, that is, a vocational training. However, as chapter two points out many thinkers, for example Plato and Bacon, did not regard learning how to do practical activities as an important or even significant part of one's education. Under the heading of education for power is the idea that education should also provide an opportunity for physical hardening, that is, sport. However, I shall not dwell on this aspect.

Finally, chapter two points out that a number of thinkers have been of the view that a liberal education has a number of disadvantages and dangers. This idea was particularly prevalent in the 15th and 16th centuries when religious organisations had a significant influence on education. However, as pointed out in chapter two, Bacon argued convincingly that this was not the case. However, with reference to modern forms of education, chapter two showed that thinkers such as Whitehead believed that many people currently overspecialise with the result that they produce superficial thought and imperfect categories of thought in all areas outside of their specialisation. This is obviously something that needs to be considered in the development of an engineering curriculum which is inherently specialist. To conclude this paragraph on the disadvantages of a liberal or general education it is worth noting that chapter two points out that modern theories of education have moved away from grand aims to more narrow educational objectives and, in addition, there has been pressure to let market forces play a greater role in education. In addition, as mentioned in chapter two, Phenix pointed out that modern education's easy acceptance of conflicting ideas can result in rampant relativism.

5.2.2 Analysis of General Educational Aims and Engineering Educational Aims

I am now in a position to analyse, in detail, the above general aims of education and the specific aims of an engineering education in order to determine how an electrical engineering education relates to accepted definitions of education. As mentioned above, this is a necessary first step towards determining the curriculum for an engineering education because once the status of an electrical engineering education has been established a better understanding will be obtained about what exactly an engineering education is and what should and should not be included in an electrical engineering curriculum.

It is clear from section 5.2.1 that an electrical engineering education does not fall easily into any of the above definitions of an education. Chapter two points out that an engineering education, in the three types of institutions under consideration in New Zealand, is governed by the Washington accord signed in 1989 which merely recommends a list of cognitive abilities that a practicing engineer should have - the web sites of these three institutions making it clear that they follow the recommendations of this accord closely. The chapter continues by noting that the major electrical engineering institutions, such as the IET and the IEEE, also recommend lists of cognitive abilities that practicing engineers need to have. No mention is made of what a student can actually absorb in a four year degree. In other words, there is a complete lack of student centeredness in these recommendations. In addition, it is not made clear to prospective engineers that an engineering education is in fact not an education since it does not fall into any of the recognised categories of education summarised above and therefore *an engineering education is solely vocational training*. It is important that this is made clear to prospective engineering students so that they can plan their lifelong education in an intelligent and informed way. Furthermore, electrical engineering curriculum designers should bare this in mind when they are devising curricula for engineers because this basic fact of engineering 'education' will influence the curriculum, how it is taught, what type of learning the students are expected to undertake, and how the students' work will be assessed. In addition, in curriculum design, more attention needs to be paid to meta-cognitive abilities such as inquiry, critical thinking, creativity, and understanding. These aspects, particularly *understanding* and *creativity* important meta-cognitive abilities for engineering students, are dealt with in more detail below in the section on *understanding*.

As mentioned above, chapter two covered the moral aims of education. Here it was claimed by many thinkers that the aim of education should be directed at achieving morality and thereby happiness. This meant that for the individual education should build character, provide a person with the correct general fundamental principles to live his or her life by; it should make one able and adaptable. Education should enable one to make correct judgements, be able to correct oneself, and be able to enter into authentic dialog. Finally, the point that education should give one good values, a balanced outlook, and wide interests. If the aims of an electrical engineering education in chapter two are studied, it is apparent that only two aims of an engineering education approximate the above moral aims. The first is that engineers should be able to "function in contemporary society" and "demonstrate personal and social skills". This aim is far too vague to have any real meaning and, in addition, as shown in chapter four where the detailed engineering curricula are discussed, there is little in the actual engineering curriculum that promotes an engineer's ability to function in the wider contemporary society. The second aim that applies to individual morality is that engineers should "act in accordance with the ethical principles of the engineering profession" and "recognise their obligations to society". This set of ethical principles is a set of principles that apply directly to engineers involved in their engineering activities. They are not a general set of principles that may be applied to one's wider societal activities and therefore do not play a major role in promoting one's general moral behaviour. It is therefore apparent that an engineering education is not aimed at and does nothing to develop an individual's general moral behaviour.

Chapter two also looked at moral education from the point of view of the state. In this section the thoughts of a number of thinkers were covered that were of the view that the aim of education should be for the benefit of the state. These thinkers felt that education should enable one to understand what citizenship means and how one can become a good citizen. In this way education would make one easy to govern but difficult to mislead and, in addition, education should be aimed at producing good leaders. These thinkers also felt that education should be used to ensure distributive justice within the state and to provide protection to the state by training warriors. The fundamental principal of their views could be summarised by saying that the individual and the state have a symbiotic relationship and each has meaning only through the other. Again, if chapter two is studied it will be apparent that none of the above aims is included in an electrical engineering education. The only engineering aims that approximate these aims are that an engineer should understand the societal implications of engineering work and his or her obligations to society as an engineer; and an engineer must be able to function in contemporary society. These aims are far too general to have any practical meaning and only apply to an engineer carrying out his or her engineering work; they do not apply to an engineer becoming a benefit to the state in any general sense.

In chapter two a number of thinkers put forward the view that the purpose of education was to be of service to god. In fact, many of these thinkers such as Saint Augustine felt that since, in their view, god was the source of all reliable knowledge and truth; educators have no choice but to make the service of god and the contemplation of god the aim of education. In this way, moral excellence will be achieved. A number of thinkers under this heading had a religious slant to their ideas in that they saw education as transmitting the knowledge that god reveals to humanity and that one should aim to reveal god in the transitory world around us. Again, there is no part of an engineering education that could fulfil this aim. A fortiori, an engineering education promotes ideas that are contrary to this way of thinking because, as the aims of an engineering education show, engineering promotes a secular scientific view of reality and not revealed truths from god. Obviously there is nothing in an engineering education that advocates the service to god as an aim. In fact, it could be argued that an engineering education promotes secular aims.

In chapter two I noted that Nietzsche felt strongly that the purpose of education should be to support the few geniuses in society who understand the society's culture and to promote the transmission of a society's cultural heritage. In addition, education should aid one to re-evaluate one's values and to be aware of the power relations within a state and a society. Again, there is nothing in an engineering education that promotes and transmits a society's cultural heritage. In fact, because engineering deals with the latest technology, it could be argued that much of what engineering produces weakens a society's ties with its cultural past by forcing people to devote significant amounts of time learning to use modern technological products that are rapidly superseded. This then forces one to learn to use the latest product thereby repeating the cycle and reducing the time people can spend on their society's culture.

As I explained in chapter two, after the renaissance, education philosophy moved away from the idea that the purpose of education was to promote the *greater good* and moral awareness to the idea that knowledge qua knowledge was the purpose of education. A liberal education promotes the idea that the purpose of education is to develop effective habits of thinking and knowing; and the idea of knowledge for knowledge's sake. Therefore, an electrical engineering education cannot be regarded as a liberal education because it has vocational aims and does not promote the idea of knowledge for knowledge's sake. Any habits of thinking and knowing that an engineering education produces are within a narrow range because it is a specialist vocational education.

Chapter two notes that an important aspect of a liberal education is that it should enable one to develop judgement, wisdom, and foresight. It should enable one to be able to judge the *method* that someone uses to justify a position even if one does not fully understand the topic being justified. In addition, a liberal education should enable one to use reason to counteract desires and to enable one to follow moral strictures such as Kant's categorical imperative. In fact, Kant believed that one of the major roles of philosophy (and presumably education) was to enable people to render a system of morals more complete. Ultimately, reason is to be used to achieve happiness. The judgement, wisdom, and foresight produced by an engineering education is restricted because, as chapter four on engineering curricula shows, an engineering education is narrowly based on mathematics and science and deals with technology. In other words, there is little in an engineering education to give one a broad view of the world and hence enable one to develop wide-ranging judgement, wisdom, and foresight as advocated by a liberal education. There is even less in an engineering education to enable one to "make a system of morals more complete" and thereby achieve happiness.

Key aspects of a liberal education, as discussed above, are to encourage one to develop a love of learning and to enable one to think in diverse ways. That is, a liberal education is a universal education that prepares one for an unknown rapidly changing future. As one undertakes a liberal education one should grow in one's universality of thought (wisdom) and develop communal ways of thinking. This allows one to "be in all that one does" and be governed by the universal characteristics of a situation and not by personal idiosyncrasies. A liberal education should prevent one from being blindly led by the past and tradition, and should enable one to use pre-suppostionless observation, science, reason, and personal experience to decide a course of action. In addition, a liberal education should allow one to enrich one's experience and develop one's system of morals by having leisure for reading, reflection, and self-contemplation: that is, sufficient leisure time for self-education. Again, as chapter two shows and chapter four confirms, an engineering education is narrowly focused and therefore meets these aims of a liberal education in a limited and circumscribed way. An engineering education cannot be said to develop universality of thought, to develop a diverse way of thinking, or to develop a communal way of thinking. In fact, if the aims of an engineering education in chapter four are studied, it is apparent that an engineering education is likely to do the opposite and develop in its learners a single faceted view of reality. In addition, an engineering education is predominantly science and mathematics based whereas a liberal education values moral development more than purely intellectual or scientific development.

The third major category of educational aims, discussed in chapter two, was that of education for power. Most of the thinkers discussed in the chapter had the view that education should be used to ameliorate the effects of power and money rather than be used to obtain power and money. These thinkers believed that paid employment degrades the mind, and that money and power distort the truth. In addition, chapter two explained that Marx argued that capitalism is alienating and dehumanising and therefore education should be used to counter these effects by producing a communal man. Finally, this chapter showed that thinkers such as Plato believed that manual skill and vocational training were not even part of a 'real' education and Whitehead argued that the type of specialisation inherent in a technical education produces an unbalanced development of one's character and that technically educated people are good at the detailed aspects of a society's development but are not good at the overall co-ordination of society's development.

5.2.3 Analysis of the Application of Chapter Two to an Engineering Education

In conclusion, what this analysis has shown is that electrical engineering courses in New Zealand polytechs and universities cannot be regarded as an education no matter what aim or definition of education one adopts. An engineering "education" is merely a narrowly focused exercise in vocational training. In addition, as chapter four shows, an engineering education is not designed to make new scientific discoveries or to develop new areas of mathematics: these functions are the role of pure mathematics and pure science. *In my view, the role of an engineering course is to train engineers to understand and creatively apply existing mathematics and science in order to develop and use technology in the most cost effective way.* It is therefore essential that the above analysis is included in an engineering curriculum. This will enable engineers to become aware of the limitations of their "education", encourage them to diversify their learning after graduating as an engineer, and to devise an informed personal education plan that will fulfil whatever each individual decides is important for an educated human being. It is possible that this will also motivate engineers to complete their engineering studies rapidly because these studies will be clearly focused on engineering and a rapid completion will allow them to get on with a real education.

This analysis has further implications for the engineering curriculum: because an engineering "education" is so narrowly focused and does not even vaguely approximate a general education and, because the volume of material covered by an engineering education is enormous, the curriculum in an engineering course should concentrate entirely on engineering topics and not attempt to cover topics that are more general (such as economics, law, environmental sustainability, etc). The reason for this, as confirmed by my own experience as an engineering student and as an engineering educator, is that the time pressures in an engineering course are so great that these non-engineering topics will be so superficially dealt with that they will be almost meaningless. This is particularly true since engineers usually have little prior knowledge in these fields which means that the material has to be covered at an almost trivial or meaningless level. Furthermore, my own experience of sitting in economics lectures while trying to studying for an electrical engineering degree was that my colleagues were not motivated to learn economics when they were trying to become engineers and therefore did not take these non-engineering courses seriously. The result of this was that minimal learning took place in these courses, the material was soon forgotten, and time was wasted which could have been better spent on engineering subjects.

Therefore, in light of this evidence, it is my view that an electrical engineering curriculum should concentrate on electrical engineering only and, as part of the engineering curriculum, it should be made clear to all engineering students that an electrical engineering degree is not an 'education': it is merely training for a vocation. That is, the above analysis should be made available to all engineers in some form or other. To leave graduate engineers with the idea that their studies have given them any form of general education is fraudulent. That is, once engineering students have finished their engineering training they should be encouraged to undertake post-graduate studies in order to obtain a more diverse education and they should use part of their leisure time once qualified as an engineer to obtain a "real" education. In other words, an engineer should view his or her education as a lifelong project and not as starting and ending during their time at university reading for their engineering degree. That is, at the start of their studies all engineering students should be made aware of the kind of material covered in chapter two.

5.2.3.1 The Time Span of an Electrical Engineering Education

As hinted in the previous paragraph, an important aspect of an electrical engineers professional and general education is that it does not take place entirely during his or her time at a university or polytech. A typical engineer's education is spread over approximately 45 years as shown in figure 5.1.

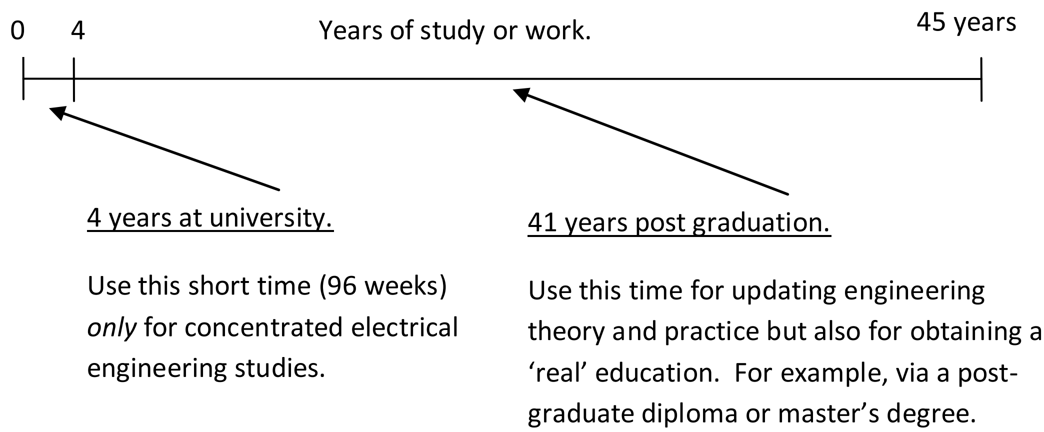

Figure 5.1 An Engineering Education Timeline.

That is, from the time that engineers go to university at the age of around 18 to the time that they retire at around 65, they should be continuously improving their *real* education. The first implication of this is that when an electrical engineering curriculum is designed it should adopt a time scale of 45 years and not just four years. The second implication is that the time that an engineer is at university should be used only for engineering studies. The reason for this is, as mentioned above, that the amount of knowledge in electrical engineering is so vast that it is difficult to do it justice in four academic years; that is, in ninety six weeks which is less than two calendar years. Therefore, this time should be spent solely on giving engineers a thorough grounding in engineering and cover material that is likely to have maximum long term benefit to engineers. That is, material that will enable them to self study in engineering throughout their career. Undergraduate engineers do not have the prior knowledge, or the motivation to undertake meaningful studies in areas outside engineering while they are undergraduates. These non-engineering subjects could be covered in a post-graduate diploma or master's degree because engineers do not have time in an undergraduate course to be vocationally trained *and* get a real education as defined in chapter two. The engineering curriculum must have clear simple objectives and stick to them. Hence chapter two is important for determining the philosophy of an engineering education and for determining the correct objectives of an engineering curriculum. Finally, a hypothesis that is not easy to substantiate but may be a minor factor in the high failure rate of engineers could be that engineers do not understand what they are getting into when they enrol for an engineering degree and become disillusioned with the degree before they complete it.

5.3 Teaching and Learning in Electrical Engineering

5.3.1 Summary of the History of Learning and Teaching

Chapter 3 sets out the various historical approaches that have been adopted towards teaching and learning. As this chapter shows, even prior to the modern era (post 1600), educators realised the importance of prior learning and the students' daily life as the starting point for any further education; the importance of a educator having a good subject knowledge; the idea that students must think for themselves and construct their own knowledge, that is, one cannot 'put' knowledge *into* another person; that initial ideas tend to be strongly held later in life and therefore analogies must be used carefully and sparingly; that experience is important in learning; that educators must match the material to the students; and that students must be motivated to learn. They also realised that different teaching methods and styles need to be adopted for different students and for different types of knowledge. Furthermore, a real education takes time because a real education must fundamentally change one, which in turn means that for an education to be truly successful it must be approached in a variety of ways and that the educator must act as a role model. Chapter three also shows that a number of thinkers, such as Montaigne, realised that much knowledge is socially constructed, although, they obviously would not have used this terminology. Finally, memorisation was seen as an important part of learning and it was appreciated that a good learning environment without compulsion was necessary.

Prior to1600 the approach adopted for education, as this chapter shows, was that of giving students the tools (the trivium and the quadrivium) to educate themselves, organising knowledge for the students, and then using a dialectical approach to teaching in order to get students directly involved in their learning.

The above ideas remained influential, with only minor changes, up to the beginning of the 1900s. However, between ca. 1600 and ca. 1900 a number of educationalists developed new ideas on education. As chapter three points out, Bacon was one of the first thinkers to re-examine past ideas in general and those of education in particular. He also noted that knowledge must not be presented as fait accompli but that students and educators should look for new ideas and methods without ignoring the lessons of the past. In addition, students must be made to realise that they are responsible for their own learning.

This chapter notes that Locke was one of the first thinkers to examine the idea of nature versus nurture; that is he was of the view that innate ability was important: an idea that has remained controversial into the 21st century. A 19th century educationalist that has had a significant influence on education well into the 20th century is Rousseau. Chapter three explains that he viewed textbooks and rote learning as an anathema, instead he saw children developing as a product of nature rather than of modern society. Some other thinkers, covered in this chapter, that have produced new ideas on education are Froebel, Schopenhauer, and Mill. Froebel believed that educators must guide self-discovery and that they should maintain close contacts with the families of the students and the community. Schopenhauer was of the view that education should follow the path that the subject originally followed when it was being developed, that is, from the specific to the general. He also believed that a few well grounded ideas were more important than many vague ones and that knowledge was mature when it perfectly matches one's life experiences; that is, learning should come from real life rather than from books.

One of the most influential educationalists at the beginning of the twentieth century was John Dewey. Chapter three explains that Dewey was of the view that shared experience was the key to education and learning: this idea was further formalised by Piaget who saw education as a dialectic between apperception, assimilation, and accommodation. That is, students must be confronted with experiences compatible with their current knowledge and level of development. Under this paradigm the educator becomes the leader of a group and the students become active learners sharing democratically in the learning process. That is, Dewey defined education as a growth in one's capacity for experience. However, in order for this process to be successful it is necessary that new experiences must be related intellectually to prior experience and have continuity, the experiences must be agreeable, and they must have a positive effect on future experiences. In addition, Dewey believed that educators must take a long term view of experiences and consider the collateral learning that takes place due to any particular experience. The implications of Dewey's ideas are that students learn from projects based on everyday life and that the classics, history, and 'inner life' are not important for education. He also recognised that a student's unique bent and interest are important and must be considered in any experiential education program. It is clear from this summary of Dewey's ideas that he saw educational growth as general human growth and was not aiming his methods at learning in a specific narrow field such as engineering. Therefore, his ideas cannot be applied, without qualification, to engineering learning as will be elaborated below. Finally, chapter three notes that Levi-Strauss took a narrower view of experience when he stated his belief that only people with practical experience of a technical subject should teach the subject and that practical experience for technical students should be real.

This chapter continues by showing that many other educational thinkers were active at the beginning of the 20^{th} century. For example, William James recognised that educators, who by their training are advanced thinkers, would be able to see the overall implications of an education topic but find it difficult to appreciate the students' problems with the topic's minutiae. Three aspects of learning that received a lot of attention early in the 20th century were learning via operant or instrumental conditioning, behaviourism, and learning by association of ideas. None of these views has remained influential in the education of humans and have, therefore, not significantly influenced engineering education.

Chapter three shows that later in the 20th century a number of ideas, such as Dewey's, underwent further development. The structuralists emphasised the idea that educational experiences were more than just the sum of their parts, that is, they followed the ideas of the Gestalt psychologists and Dewey. According to the structuralists, educational experiences start off being unstructured and confusing, and slowly become more structured and meaningful as understanding is developed. The educator is therefore an encourager, example provider, co-analyser, and co-builder of mental structures. The student must be active in this process and the educator modifies the student's constructions. In addition, the structuralists believed that each area of human knowledge has its own unique structure and should be taught taking this into account.

Later in the 20th century the ideas of constructivism were formalised. As chapter three explains there are various levels of constructivism. An individual may construct completely new knowledge via a consilience of inductions from nature as in the case of an Einstein; or an individual may construct his or her own knowledge paradigm based on already existing knowledge such as takes place in most educational systems; and then there is knowledge that is socially constructed such as the moral norms and laws of a particular society. It is usually the second type of constructivism that is of relevance in the education of students. In the second type of constructivism the students know that their own personal knowledge paradigm is useful when it accords with and can accurately predict the outcome of their experiences. Therefore, learning becomes a social process in which the students attempt to make sense of their experiences by using critical reflection and prior knowledge. The role of the educator is to understand the students' current knowledge paradigm and then to provide them with new experiences that cannot be explained using the students' current knowledge constructs. The educator then leads the students in a process that bridges the gap between their current knowledge and the new experience.

5.3.2 Summary of Modern Learning Theories

Chapter three presented a range of theories that have been thought to promote learning. In this section it was pointed out that curiosity and interest are important motivating factors for initially undertaking learning; that learning should produce thinkers, critics, organizers, and creators not just 'storehouses' of facts; that learning is a cycle of teaching and thinking (discovery, construction of knowledge, and problem solving); and that the actions of the educator are important for the success of the students. Therefore, for learning to take place students must be interested and motivated; and an educated person is one who knows how to do things, why things are the way they are, and is able to self educate. This chapter also pointed out that assessment has a number of functions. It enables an educator to determine the level of the students' knowledge and abilities, the difference between students' knowledge and abilities, and to diagnose problems with the students' learning. In addition, chapter three noted that, although learning is a complex matrix of occurrences, there does not appear to be any limits to human learning, and that the learning of different cultural groups appears to be similar.

Chapter three continued by pointing out that the learning environment, both external and internal to the students, affects how students think about a subject and is important for their success. In other words, educators should carefully consider the students' cultural practices and beliefs as well as their prior knowledge: bearing in mind that prior knowledge can both help and hinder learning. Finally, chapter three showed that for learning to take place a student's curiosity must be awakened and then new knowledge must be 'knitted' onto old knowledge. In addition, it is important that students develop a love of learning and accept responsibility for their own learning; that is, they must develop an attitude of intelligent doubt and feel free to dispute points of contention.

The psychological factors involved in learning were also dealt with in chapter three. This chapter noted that an area in which extensive research has been carried out is that of *memory*; although it is interesting to note that the basis of memory, the engram, is still not known. First, one remembers best if the knowledge being remembered follows a set of related steps, for example, an engineering formula is easier to remember if its derivation is known. This means that a fact that is part of a factual structure is more likely to be remembered than an isolated fact; that is, one must think about one's knowledge and inter-relate one aspect of knowledge with another. Therefore, memory is an organised information structure, often involving imagery, and not just a set of facts. This explains why 'cramming' for an examination is a waste of time: the knowledge is a series of isolated facts and therefore will not be remembered for long. Second, continuous application is important for making memories permanent; that is, rehearsal improves long term memory although other learning can interfere with these memories. In addition, distributed practise is better for memorising than one continuous practice and distinguishing the relationships between facts is better than mere repetition. Third, memory is a prerequisite to reasoning, recognising problems, and applying experience. Fourth, memory may be aided by mechanical methods such as 'chunking' and mnemonics; however, it is doubtful whether these techniques are of any real efficacy in everyday life. Fifth, it is important to bear in mind that *recall* does not recall an actual event but merely recalls one's previous recall of it. Sixth, forgetting is affected by new memories influencing old ones and vice versa. For example, memories are affected by context; it is often hard to remember something when one is in a completely different context. Finally, it is worth noting that the rate of learning and the rate of forgetting do not seem to be related.

A psychological factor mentioned in chapter 3 that is important to teaching and learning is that of the concept of *transference*. Unfortunately, as chapter 3 showed, only limited transference is possible from one educational topic to another - that is, transference is only possible if common factors exist between topics. The amount of transference that takes place depends on the learning context and the type of learning considered. The unique aspects of each topic need to be learnt.

The next psychological learning factor to be considered is that of *symbols*. Chapter three explains that definitions and concrete symbols aid learning. Symbols allow abstraction and high level analysis, rapid thought, and the linking of ideas; that is, developing short cuts. However, although symbols promote abstract thought they may inhibit the students learning to apply ideas and educators may confuse symbol manipulation with education.

A psychological aspect of learning that has produced extensive debate is that of *nature versus nurture*. Chapter 3 explains that intelligence is difficult to define but is usually regarded as one's ability to learn from experience, to adapt to one's environment, and the ability to solve problems. Most psychologists regard intelligence as comprising a number of measureable components such as language ability, arithmetic ability, spatial ability, etc. However, intelligence also consists of a number of meta-components which are difficult to measure such as social skills, persistence, motivation, etc. For this reason the balance between genetically determined intelligence and intelligence promoted by learning (nature versus nurture) is difficult to determine.

One of the objectives of most modern education ideologies, as explained in chapter three, is the promotion of *thinking skills*. However, as this chapter points out one can usually recognise the results of good thinking skills but it is not clear how an educator can reliably teach thinking skills. Thinking is the process of making a mass of simple inferences so that private hypotheses of perception and shared hypotheses of conceptions make up one's reality. In addition, thinking involves deciding, judging, prioritising, perceiving relationships, having vision, being able to focus one's attention, being able to order information, and being able to memorise. Psychologists have been able to show that inefficient thinking is point to point thinking (if A then B, and if B then C, etc), or thinking that does not explore a point of view, or thinking that uses logic based on incorrect perceptions, or a combination of these approaches. Good thinking involves using imagination and imagery, and being able to direct one's attention to a problem or concept; that is, looking for the positives, the negatives, and the interesting aspects of a point of view. However, it should be noted that lateral thinking is difficult to do because it is difficult to break out of old paradigms. In addition, independent or lateral thinkers are rare and are often ridiculed by more conventional thinkers.

Chapter three continues by noting that experts have extensive knowledge and therefore notice different things. They organise, represent, and interpret information differently to non-experts. This process in turn positively affects their ability to remember, reason, and solve problems with the result that experts do not just have knowledge but also have the ability to apply it. In general, notwithstanding the comment made above, experts seem to be able to transfer knowledge from one field to another possibly because rote memory rarely promotes the transfer of knowledge whereas understanding does.

Finally, chapter three notes that for students to develop good thinking skills they should be aware of themselves as learners; that is, be aware of the meta-cognitive aspects of learning so that they can learn how to learn and become reflective learners. In addition, educators should guide this process and help to remove misconceptions; that is, they should guide attention, structure experiences, support learning attempts, and regulate complexity and difficulty.

The next psychological aspect of learning that chapter three deals with is that of the *creative use of knowledge*. Teaching is fundamentally the process of aiding students to construct understanding and then to use that understanding creatively and wisely. Unfortunately both of these concepts, understanding and creativity, are difficult to understand and difficult to teach. Taking creativity first: creativity is hard to define comprehensively but it usually involves bringing something new into existence. There does not appear to be any correlation between high I.Q. and creativity, however, the tension in humankind between maintaining the status quo for peace of mind and the desire for new experiences seems to produce creative acts. In other words, convergent and divergent thinking is needed for creativity. In addition, creative people respect the irrational and intuitive in themselves. Education that promotes unorthodox thinking may foster creativity but it does not guarantee it.

Chapter three notes that creative thinking does not typically follow a fixed logical sequence but it does seem to involve the following processes to a greater or lesser extent. The creative person initially explores the resources at hand after which a period of incubation usually follows and out of this, occasionally, an experience of illumination, that is an idea, results. After the illumination or creative idea has been produced a period of verification and refinement is usually undertaken. As mentioned in this chapter, reliable objective tests for judging creativity do not exist so that the criterion for judging creativity then becomes the opinion of the creator, that is, the creator's emotional satisfaction. The quality of creative thinking, however, *does* seem to depend on the training of the creator.

One of the difficulties in understanding creativity, in promoting creativity, and in researching creativity is that a significant part of the creative process takes place subconsciously. It is not clear what this subconscious process is or what the best methods are to enable it.

5.3.2.1 The Nature of Understanding

Ultimately any form of real education is fundamentally the process of aiding students to construct a workable understanding of a particular topic or subject and applying this understanding in a creative way. However, as with creativity, the nature of *understanding* is not understood. Section 3.3.3 is the most important section of this thesis because it deals with understanding which is an important objective of any level or type of education.

This section points out that the importance of understanding has been understood by most writers in the field of education from the time of Plato to the present day. In addition, it is difficult to assess a student's real understanding of a complex topic. However, this problem, may not be as pronounced in the mathematical and scientific fields because mathematical and scientific concepts, although creations of the human mind, are embedded in a system of logical necessities and consequences that relate to other mathematical and scientific objects producing a consilience of inductions.

Nevertheless, one's own conceptions and understandings influence how we interpret other peoples' understanding, that is, there are no objective truths about other people's cognitive constructs. Therefore an iterative process is necessary in order to understand a student's understanding; for example, one must develop a theory or model of a student's understanding and then test this model in many different ways. As discussed in section 3.3.3, Treagust, Duit, and Fraser (1996) are of the view that little is known about the process of how a student understands something, but understanding seems to be fostered by informed purposeful activity and when students have control over their personal learning approach. However, no set strategies can guarantee to improve understanding in the classroom. Interestingly, this section noted that Solomon observed student discussions on scientific topics and found that the students did not know what knowledge sources they were using to construct knowledge during these discussions. Finally, section 3.3.3 notes that it is difficult to conceive of an objectively good or correct understanding of something; for example, how would one practically check that a student's understanding does not contradict any statement of a particular scientific or mathematical theory? There may be an infinite number of statements that could be made about any particular theory. It is much simpler to prove that a student's understanding is not perfect because, for this, only one contradiction is required.

To further summarise section 3.3.3, is it not only difficult to understand what degree of understanding a student has constructed in a particular field but the fundamental concept of understanding is difficult to comprehend. The infinitive verb 'to understand' is ambiguous and has many meanings. For an act of understanding to be less ambiguous one must know what is being understood; on what basis is it being understood, that is, via reason or via empathy; and the operations of the mind that are involved in the act of understanding. In addition, one needs to understand the environment that the concept to be understood is embedded in; that is, understanding is usually contextual rather than merely formal inferences from general and abstract statements. However, a further complication with the concept of understanding is the fact that meaning and understanding are intertwined concepts and, as with understanding, meaning is hard to define - probably due to its self-referential nature, that is, a definition of meaning has to have meaning. Generally one may view understanding as being in one's mind whereas meaning is in the public domain. It is clear from chapter three that there are many views of understanding with the result that even seminal educationalists such as Piaget have had difficulty with the concept. His theory of equilibration produced the rather weak statement that one has understood when one has a feeling of order and harmony in one's thoughts. Positivist thinkers, however, disagree with this view and believe that one must observe the facts, state the regularities of co-existence and succession of phenomena, and based on these regularities one must make one's predictions and base one's technology. Many mathematicians and scientists, on the other hand, regard something as understood if one can build an accurate mathematical model of it. In other words, understanding is based on the ability to do something. However, mental models of reality can become confused with reality and, in addition, one can occasionally predict future events correctly using an incorrect understanding of the underlying phenomena. Conversely, 'suchness' understanding takes the opposite view that sometimes one just understands something because it is as it is and one does not ***do*** anything with this type of understanding, for example, understanding a picture, a poem, or a piece of music. Ultimately, understanding may be difficult due intrinsic reasons as described above or due to the fundamental nature of the universe around us; that is, extrinsic reasons.

However, as section 3.3.3 showed, it has been postulated that understanding has four mental operations (although this will be refuted when Wittgenstein's ideas are discussed below): (a) identification, discovery, or recognition of the object to be understood; (b) discrimination of the object, that is, recognising that it is different from other objects; (c) generalisation; and (d) synthesis. The synthesis may be regarded as a local synthesis as in a particular aspect of mathematics or science, or it could be regarded as global syntheses such as those which have paved the way to the unifications that mathematics has experienced over the last two centuries. In education a difficulty arises because the synthesis has to be made by the understanding subject and not by the educator. Understanding is, therefore in this sense, an active process and our minds are not passively imprinted with ideas of things from the outside. The student is the agent whose relation to the object of understanding is mediated by his or her own activity. As a result of the action of the student on the object, a new object of understanding may come into being, that is, the student has produced or constructed something. In this view of understanding attention focuses on the transformation and the production of objects as a result of student activity. Furthermore as section 3.3.3 points out, understanding is built in a complex dialectic process between action and reflection upon the action. Development starts with an action on objects; it then goes through making connections between objects, and ends with a perception of and reflection on a whole structure. Under this process none of these stages can be skipped if a conceptual understanding is to develop.

In addition to the above four mental processes section 3.3.3 noted that the necessary, but not sufficient, conditions for understanding something are; (a) something to be understood needs to be brought to one's attention, however, if one is not familiar with a particular topic one will not know what to attend to, (b) one needs to be puzzled about it, that is, to have a question brought to one's mind, and (c) the process needs to take place in a social environment of some form. The first step of attention may be applied on a meta-level. In other words, attention may be applied to how we are going to go about solving a problem. However, in education it is difficult for the educator to communicate what should be attended to. There have been many cases of sudden illuminations or unexpected acts of understanding something that one was not thinking of at a particular moment, that is, some form of processing has been taking place unconsciously. These sudden acts seem to contradict the idea that for understanding something needs to be brought to ones attention. However, most people who have had these experiences have been assiduously attending to the 'problem' for an extended time prior to the sudden event even if they have not been thinking about the problem at the moment of illumination.

As section 3.3.3 points out, improving understanding in mathematics and science education has traditionally been approached in three ways. One approach concentrates on developing teaching materials and technology that would help students to understand better, another concentrates on diagnosing or assessing the students' understanding, and a third attempts to build models of how the students understand. Sierpinska, on the other hand, does not believe any of these methods are truly successful and has developed the idea of 'obstacles' leading to understanding. She argues that acts of understanding that overcome an obstacle, whether developmental or epistemological, are the most important for developing understanding. These obstacles are subjective and varied, for example, they may be due to the difference between scientific thinking and language, and everyday thinking. However, it is difficult for an educator to know what obstacles a particular student is trying to overcome and an added complication is that once the obstacle has been overcome previously developed ways of understanding may have to be modified by the student making the whole process complex. Chapter three continues by noting that Sierpinska believes it is necessary for an educator to provide challenging questions and problems to students so that a 'gate to conceptual thinking' is opened for them. The educator must lead the student's thinking beyond the forms of thinking that he or she is using and force it into forms of thought that are more elaborate. This in turn will sow the seeds of further epistemological obstacles to be overcome and a deeper understanding will develop.

A careful reading of this chapter highlights the fact that most of the thoughts and ideas mentioned are not new. In fact, a salient meta-thought to come out of this current chapter of summaries is the clear fact that few significantly new ideas have been produced in education since the time of the ancient Greeks. However, as section 3.3.3 points out, one person has done more to influence the above discussion and produce new paradigms of thought than anyone else, namely, Ludwig Wittgenstein. He noted that it is not simple to understand how statements get meaning which implies that large parts of education are puzzling. He was interested in and investigated what is meant by, and what the differences are, between knowing, understanding, and just blindly following a rule. ***He showed that understanding is not a mental process, such as pain that becomes more and more***

severe, because one suddenly understands something without a 'process' taking place. For example, what actually is the process of reading? When one sees a word that one knows one immediately understands it, there is no *process* of understanding that takes place. Wittgenstein developed, amongst many other things, the concepts of a language game, of private languages, and of understanding not being a mental process.

For example, the concept of a language game, put simply, means that for a student to fully understand a field of study, say electrical engineering, the student must understand the environment, in the broadest sense, that the field of study inhabits. That is, the student must understand the jargon, the symbols, the slang, the abbreviations, and the short cuts used by professional engineers. It is this total environment that Wittgenstein was referring to when he referred to a particular activity having a particular language game. A student who does not understand the 'language game' of engineering will have great difficulty in communicating with other engineers and really understanding engineering concepts. Therefore one of the fundamental parts of an engineering education will be the students developing a comprehension of the language game of engineering.

The second of Wittgenstein's concepts, that of a private language, has implications for western philosophy and for western education. As section 3.3.3 mentions, Wittgenstein showed that an *entirely* private language is not possible. Applying this idea to education means that radical constructivism is not possible, which in turn means that some form of objective reality must exist. We may not have an accurate model of this reality but it must nevertheless be there. The implications of the impossibility of private languages for teaching and learning are extensive. First, it means that students can only construct meaning by interacting with the physical world, their peers, remote authors, and with society. They cannot construct real meaning *entirely* on their own. Second, it means that curricula must be structured so that students have a range and a variety of options for constructing understanding because no one approach will provide the full range of interactions that a student needs in order to develop a deep insight into a particular topic.

The third of Wittgenstein's concepts, that of understanding not being a process but being a mental event also has extensive implications for teaching and learning. If understanding is not a process but a sudden event then it is difficult to structure teaching so that these events will take place because it is almost impossible for an educator to know precisely what learning activity will trigger understanding in a particular student. This is true because there is no understanding of how this event comes about or even what it is exactly. There are many documented cases of people having eureka moments but there does not appear to be any explanation in the literature of what exactly these events are, what causes them, or how they can be reliably produced. In other words, educators have no guaranteed way of ensuring that students will understand a particular topic and that their teaching will be successful in any situation other than the most trivial. Wittgenstein's ideas are fundamental to education and will be fully discussed below.

It was mentioned above that Sierpinska postulated that understanding in mathematics and science can be improved in three ways: using appropriate teaching materials and technology, using diagnostic techniques, or building models of students' understanding. However, if the occurrence of understanding is not a process then it is difficult to know what type of teaching materials and technology to use and the diagnostic techniques will at best show that limited understanding has occurred but will not explain why it occurred or what exactly caused it to occur. As mentioned in section 3.3.3 diagnostic techniques such as getting the students to undertake some activity that requires the understanding or getting them to build a physical or mathematical model can be misleading; that is, they may give inaccurate evaluations of the depth of a student's understanding. In addition, it does not measure understanding because understanding is prior to a student's ability to do something. That is, it is a physical manifestation of a small part of a student's understanding.

To date no one seems to have been able to develop a model of how a student's understanding occurs. This lack of a model is probably because models model processes which are distributed in time whereas understanding is a sudden event that is not distributed in time. In addition, understanding often comes about in, what appears to be non-logical, random, and sub-conscious ways. Furthermore, it is difficult for the individual to know when he or she has understood something, that is, how can one be certain of one's own understanding let alone try to model someone else's understanding.

Another conclusion that can be drawn from the above is that the modern educational emphasis placed on a student's prior knowledge as a starting point for further learning is idealistic. This is because it is difficult to comprehensively assess a student's understanding of all but the simplest topic. A complex topic would require a large number of questions to be asked of the students in order to determine whether they completely understood the topic or not. Therefore, at best, an educator can have only an approximate understanding of a student's prior knowledge and understanding, and therefore only an approximate idea of where to start with any further learning. This problem is further exacerbated in large classes and with diverse groups of students. In addition, an educator has no reliable way of determining just how approximate his or her knowledge is of a particular student's prior knowledge and understanding.

It is therefore clear that much of the modern educational theory seems to be logically cogent but is practically difficult or impossible to implement. In summary, the modern approach is for the educator to start from prior knowledge and understanding, provide a stimulating educational environment, provide students with educational experiences that build on their prior knowledge and understanding in order to extend their learning, and integrate assessments into the learning in order to provide feedback to the students and the educators. However, most of the steps in the modern approach to education are difficult or impossible to implement with any degree of certainty that the educator has adopted the correct approach for a particular student or group of students because understanding is not a process, it is not known what triggers it in a particular individual, and it is difficult to assess complex topics. This probably explains why Treagust, Duit, & Fraser (1996) mentioned that mathematics education has not improved during the 20th century, that is, educators are missing something fundamental when it comes to mathematics education and, by implication, engineering education. Finally, it is interesting to note that the above explains why knowledge learnt by rote and knowledge involving rule following is so much easier to ‘teach’ and assess than knowledge involving complex understanding.

The conclusion that the above leads one to is that educators must create a large and diverse range of learning situations for students to interact with and hope that something triggers understanding. In addition they must provide a large and diverse range of assessments in order to get some (vague?) idea whether the students have understood a topic or not. It is therefore clear that in order to carry out these activities the educators must have an *excellent* subject knowledge.

5.3.3 Summary of Modern Teaching Theories

Chapter three sets out the historical approaches to teaching and these may be summarised as follows:

- The ancient Greeks such as Socrates and Aristotle taught using a maieutic process in small groups, that is, a form of dialog between educator and students, or among students.
- During the renaissance most teaching took place using an apprenticeship approach that involved extensive trial and error.
- Subsequent to the renaissance and up until the late nineteenth century the approach adopted was that students were told a piece of information by the educator and then they were required to memorise it.
- More recently teaching has become a form of dialog between the educator and the students, or among groups of students. In this process the students must be allowed to think for themselves and to be able to make mistakes in a supportive environment. That is, education has gone back to the principles used by the ancient Greeks. In addition, recent scientific teaching has involved the teaching of the results of an (scientific) inquiry and then the students are expected to get more results using similar methods of inquiry after which the students are expected to evaluate their results.

An important fact, mentioned above, relating to contemporary education is that the teaching of mathematics and science has not improved during the 20th century (This view is expressed by a number of authors. See; for example; Treagust, Duit, & Fraser (1996); and Heitmann, John, van Oort, & Waszcyszyn (1995)).

5.3.3.1 Summary of the Types and Methods of Teaching

As chapter three details, a number of factors seem to be common to good teaching. First, before any teaching can take place an educator must attempt to get as comprehensive a knowledge of the students' prior knowledge as possible: bearing in mind the difficulties mentioned above. This is necessary because it is reasonable to assume that students construct new knowledge based on their prior knowledge; that is, prior knowledge must guide curriculum design and subsequent teaching. An approximate idea of a student's prior knowledge can be obtained from diagnostic tests; however, again as mentioned above, these tests are difficult to design for complex topics.

Second, before any effective teaching can be undertaken the students must be interested and motivated. If these two prerequisites are fulfilled then teaching may be undertaken because the educator will have a good understanding of his or her students and the students will want to learn. That is, students can then be taught to think *about* their concepts in order to make conceptual change take place and not just think *with* their concepts. Good teaching usually involves some form of cognitive conflict in order to promote conceptual change. In order to promote this cognitive conflict learning tasks should be simple, of value to the students, and have surprising outcomes that make the students think. In fact the students should be encouraged to predict the outcomes of the tasks before they are undertaken.

Finally, good educators guide the students to construct their own concepts by using multiple approaches and perspectives in their teaching to create the required cognitive conflict and trigger understanding in the students. Multiple approaches to a topic however are only possible if the educator has extensive subject knowledge as well as pedagogical knowledge. Good subject knowledge is a *necessary* condition for one to be a good educator. That is, educators must know the relationship between the core concepts in their subject and know which parts are difficult to understand and which are not. This type of judgement comes with extensive subject knowledge and with extensive experience.

Chapter three continues by discussing some particular methods of teaching. Although the methods that may be used by educators are many and varied the following are some of the most common approaches adopted. First, educators often use analogies; however, these can be dangerous because prior knowledge is strongly held and analogies can over simplify concepts or in the worst case produce incorrect concepts. These incorrect concepts may then prove difficult to change when the students study the topic at a more advanced level. In addition, one is never sure about what a student takes away from an analogy.

Second, modern technology is being used more extensively as a teaching aid. However, although these aids can be used productively an educator is still required to interpret what a technology aided learning (TAL) package is producing. TAL packages are particularly useful for helping students to visualise difficult concepts by using still and moving images. They are also useful for providing access to large amounts of information. Nevertheless a maieutic process is still necessary for good learning to take place particularly if the topic is complex.

Third, teaching should be content specific. For example, if one is teaching poetry or mathematics the teaching must be approached in context, that is, mathematics techniques should be taught as well as the particular mathematics.

A fourth specific teaching method is that of contrastive teaching in which students undertake a learning exercise involving open ended problems and their results are then discussed by the class and the educator. The educator’s role is to point out inconsistencies in the students results and to get the students to reflect on these inconsistencies. As detailed in chapter three this approach has many aspects in common with critical constructivism and Habermas's ideas of communicative action.

Finally, the idea of team teaching has been mooted. In this approach a large group of students is taught by a team of educators. The idea behind this method is that it will make better use of each educator's potential in their subject area. As mentioned in chapter three a number of forms of this approach have been adopted, however in all these forms comprehensive and detailed planning is necessary for team teaching to be successful. Ultimately, however, one constructs knowledge slowly on one's own.

As a concluding comment chapter three notes that during the 20^{th} century numerous attempts have been made to make teaching subject to the 'market'. In this approach it is hypothesised that a free market for teaching skills will reward good educators and reduce discipline problems because if a educator is good the students will be interested and not misbehave. However, this approach has had limited success when it has been implemented possibly because it is hard to define 'good teaching' and in the engineering field the professional organisations limit the role that the market can play in determining which organisations are permitted to train engineers.

5.3.4 Analysis of Learning and Teaching as Applied to Engineering Education

5.3.4.1 Introduction

Section 5.2.2 characterises electrical engineering studies as merely vocational studies. They do not produce a 'real' education. In addition, chapter 4 shows that the requirements of an engineering education are to enable an engineer to understand and to creatively apply scientific and mathematical knowledge. An engineer is not a scientist or a pure mathematician, that is, an engineer is not expected to construct new scientific or mathematical knowledge. In fact, as a perusal of any engineering text book will show the knowledge used by engineers is predominantly knowledge that has been available since the end of the 19th century (for example; Sarma, 2001). In fact, modern electrical engineering is based on the following set of equations which were thoroughly understood by the beginning of the 20th century (Feynman, 1965):

Maxwell's equations,

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$

$$\nabla \cdot \boldsymbol{B} = 0$$

$$c^2 \nabla \times \boldsymbol{B} = \frac{\boldsymbol{j}}{\varepsilon_0} + \frac{\partial \boldsymbol{E}}{\partial t}$$

Conservation of charge, $\nabla \cdot \boldsymbol{j} = -\frac{\partial \rho}{\partial t}$

Electromagnetic force law, $\boldsymbol{F} = q(\boldsymbol{E} + v \times \boldsymbol{B})$

Mechanical law of motion, $\frac{d\boldsymbol{p}}{dt} = \boldsymbol{F}$

The law of gravitation, $\boldsymbol{F} = -G \frac{m_1 m_2}{r^2} \boldsymbol{e_r}$

(These equations use conventional symbol definitions.)

Similarly, a perusal of the same engineering texts will show that the mathematics used in electrical, electronic, and computer engineering has been well understood since the beginning of the 20th century. What this implies is that electrical engineering education is predominantly the transfer to students of well understood, well tested knowledge that has satisfied a consilience of inductions over an extended period of time and that the key to teaching electrical engineering is devising methods that assist students in coming to an understanding of this knowledge: an understanding that mirrors the understanding of a professional engineer. There is little freedom in the *fundamentals* of engineering for students to construct their own *unique* knowledge. This in turn means that the teaching approach that can be adopted is predominantly that of mass lectures backed up by tutorials and laboratory work. Furthermore, students must understand the language games of engineering (its terminology and jargon) to be an engineer.

The following sections analyse the methods and techniques that may be applied to the teaching and learning of electrical engineering and hence to the designing of the engineering curriculum.

5.3.4.2 Analysis of the Historical Methods and Techniques of Learning and Teaching as Applied to Engineering Education

Due to the nature of engineering knowledge discussed above certain methods and techniques from the history of teaching and learning are applicable to engineering education and others are not. I will begin by analysing the methods and techniques summarised in section 5.3.1 above.

The history of learning theory shows that in all forms of education, including engineering education, knowledge of the students' prior knowledge is important. Therefore teaching, learning, and curriculum design in engineering must take prior knowledge into account and use the students' prior knowledge as a starting point for all further learning. Closely related to a student's prior knowledge is the fact, recognised for many centuries and discussed in section 5.3.1, that the ideas and concepts constructed by a student in his or her early years are strongly held and *difficult to change*. This implies that the teaching and learning that is undertaken in schools must be done with care to ensure that students do not construct incorrect or misleading concepts in science and mathematics. From personal experience I have found that it is difficult to change students' concepts once they have reached the tertiary level.

An important lesson from the history of teaching and learning is that experience is important for learning. Section 5.3.1 points out that many historical thinkers have emphasised this idea. This means that in engineering education the educator must provide many and diverse experiential opportunities for the students to experience engineering concepts. This may be done via traditional laboratory exercises, problem based activities, design projects, site visits, etc. As discussed above, Dewey explains that it is important that these activities are carefully designed. In the engineering context this means that the experiential activities must reinforce engineering concepts rather than try to simulate what takes place in industry because it is important that the students' engineering concepts are well ground. Tertiary education should concentrate on giving the students a well grounded foundation of engineering knowledge rather than to try to simulate what happens in industry because the students will have plenty of time to see what happens in industry once they start working. However, they will not have much time to study basic engineering concepts once they start working.

Historical methods of teaching and learning, as discussed in section 5.3.1, usually involved extensive memorisation of facts. Engineering educators should not treat the memorisation of facts as an anathema because for engineers to discuss engineering topics, to creatively use engineering concepts, and to solve problems it seems likely, as discussed below, that it is advantageous for them to have as much fundamental engineering knowledge committed to memory as possible.

The history of teaching and learning points out that a supportive nurturing environment is important for learning to take place. Therefore, in the engineering context, it is necessary for the engineering curriculum to accommodate this aspect. For example, this accommodation could involve lectures and experiential activities taking place in a supportive environment and opportunities being provided for individual students to discuss their difficulties. These individual discussion opportunities could be provided via tutorial sessions run by post-graduate students. This will aid the undergraduate students but will also help the post-graduate students to consolidate their knowledge.

One of the fundamental lessons that can be learnt from the history of teaching and learning is that educators must adapt their teaching to the students and the materials they are trying to teach. This means that engineering educators must have a thorough knowledge of the students' prior knowledge as discussed above. However, as far as the actual teaching of engineering students is concerned a number of the historical methods and techniques mentioned in section 5.3.1 may be profitably adopted. In this section many historical educationalists noted the importance of the educator having sound subject knowledge together with some practical experience. This is particularly important in engineering education due to the enormous number of basic concepts that have to be understood. As discussed below, it is necessary for an educator to be able to approach a particular concept from a number of perspectives, to use a number of techniques, and use a range of materials in order to assist the students to construct an understanding of a concept. This will be possible only if the educator has a thorough knowledge of the topic. In addition, although students ultimately construct their own understanding of a topic, it is necessary that the educator be able to assist the students to correct any understandings that do not correlate well with accepted engineering knowledge. That is, as discussed above, engineering knowledge is unlike the knowledge in many other fields because engineering knowledge is not debateable to any large extent. Engineering knowledge, or at least its basic concepts, all stem from well tried and tested 19th century mathematics and science, and therefore do not leave much room for discussion or doubt. These facts in turn determine how engineering should be taught and make it clear that the teaching of engineering must be different to the teaching of the humanities or the social sciences, etc. That is, the method of teaching must be adapted to the topic being taught. This means that a Socratic maieutic approach to teaching engineering is not ideal nor would the ideas of Rousseau, and his naturalistic ideas of education, be suited to the teaching of engineering. In addition, discovery learning is not easy to adapt to engineering education due to the number of concepts that the students would have to 'discover'. This point is highlighted when it is recalled that a genius such as Faraday took almost a decade to discover his law of electromagnetic induction which is just one concept, albeit an important one, in electrical engineering. Similar comments apply to Piaget's ideas of democratic learning and to the ideas of learning from one's life experiences. As far as the second point is concerned, most students do not directly experience the fundamental engineering concepts in their daily lives. Finally the historical idea that knowledge is a socially constructed set of concepts has limited application in engineering due to the tried and tested nature of engineering fundamentals. However, social interaction can be a useful, although limited, aid for students to help them to construct an understanding of the tried and tested engineering concepts. In order to develop this process, tutorial sessions run by post-graduate students can provide a social setting in which constructed understandings of concepts covered in lectures and laboratory sessions can be tested, discussed, and modified.

A number of student related lessons can be learnt from the summary of the history of teaching and learning in section 5.3.1. The first lesson is that for effective learning to take place the students must be interested and motivated. It is difficult to lay down any solid recommendations for motivating students due to the number of variables involved. Nevertheless, educators must be aware of this fact and endeavour to use creative methods to keep the particular group of engineering students that they are dealing with - motivated and interested. The second lesson that may be learnt from section 5.3.1 is that the material being taught must be matched to the cognitive level of the students. Again this comes down to the educator having a thorough knowledge of the students' knowledge and using the students' knowledge as the starting point for any further learning.

Two further student related ideas for engineering education that result from section 5.3.1 are the following. First, because students spend a brief time in tertiary engineering education (typically 96 weeks of actual study), this short period should concentrate on giving the students the fundamental theoretical background necessary for them to continue educating themselves in engineering once they have left the tertiary environment and have started working as engineers. This means that the engineering curriculum must concentrate on the fundamental aspects of engineering science and mathematics, that is, the aspects of engineering education that are not likely to change rapidly. Obviously the curriculum cannot consist entirely of fundamental theory but must include some of the latest technology in order to give the students practice at using modern technology and to maintain their interest. However, the emphasis of the curriculum should be on the fundamentals. Second, the students must realise that they are responsible for their own learning. They are the only ones who really know whether they have constructed an understanding of a concept or not. Assessments can highlight completely incorrect concepts but it is difficult for assessments to diagnose the extent of a student's understanding when the understanding is partial: particularly if the concept under consideration is complex.

5.3.4.3 Analysis of Modern Theories of Learning as Applied to Engineering Education

Many of the modern ideas of learning are similar to the historical ideas or are slight modifications of them as summarised in section 5.3.2. First, modern teaching theory emphasises the importance of educators having a thorough understanding of the students' prior knowledge both from the point of view of prior knowledge being the starting point for further education and from the point of view of previously held concepts being a hindrance to further education if they are significantly incorrect. Second, for effective learning to take place the students must be motivated, interested, and have their curiosity level raised. Third, the learning environment must be supportive and encouraging. Fourth, the students must be responsible for their own learning. The role of the educator is to organise the knowledge that is to be covered and to guide the students to becoming a self-educators, that is, they must learn to love learning. Fifth, during the 20th century a significant amount of work has been done on human memory. Amongst many other findings this work has confirmed the historical idea that memory is prior to following a line of reason, to recognise problems, and to applying experience. Therefore, as mentioned above, committing some basic knowledge to memory is essential to functioning as an engineer. Sixth, assessments must be used to diagnose learning - not just to promote students or rank students. All of these points have been covered above and apply to engineering education and the development of the engineering curriculum.

An historical idea that the study of memory has extended is that of the importance of the structure of knowledge for learning that knowledge. Section 5.3.2 explained that in order to retain memories the knowledge that those memories is based on must be structured and interrelated. Therefore an important role of the engineering educator is to structure and interrelate knowledge for the students, that is, the curriculum must be designed such that this is one of its aims. It therefore follows that random chunks of unrelated knowledge are hard to remember and therefore have no long term use or function. In addition, the work on memory has shown that images are a powerful means for helping students to understand and memorise concepts. This is an aspect of education that modern technology has made far easier to implement because both still and moving images may be easily incorporated in all types of education delivery. In particular, engineering education may be profitably supplemented using images to highlight concepts: particularly concepts that involve motion or more than one dimension, or both. Ideas from memory research that have limited application in engineering learning are the ideas that one can use mechanical methods, (for example mnemonics) to aid memory and that one can make memories more lasting by continuous repetition. The use of mechanical methods for memory improvement is difficult to apply to real learning and there are not many aspects of engineering that can be learnt by continuous repetition.

Much of engineering education involves the manipulation of symbols. Section 5.3.2 points out that symbol manipulation can be a powerful tool for education; however, it must be used with care because students can easily lose track of what their overall aim is and become involved solely with the manipulation of the symbols. Therefore, engineering educators must always be aware of this negative aspect of symbol manipulation and make the students continuously cognisant of what it is that they are trying to do with the symbols.

Section 5.3.2 notes that modern learning theory has shown that teaching thinking skills and teaching creativity (or lateral thinking) are difficult; which is unfortunate because both of these functions are required by engineers. In addition, these aspects are hard to assess reliably which makes teaching them even more difficult because it is difficult for the educator to measure how successful his or her teaching has been and what can be done to correct it if it is not successful. It appears, from modern learning theory, that if unconventional thinking is encouraged by the educator and the curriculum then the probability that the students will be creative is increased. However, there is no guaranteed that the students will be more creative.

An aspect of learning that modern theory has emphasised is that of students becoming aware of their own learning, that is, they must become reflective learners. The students must learn to organise their knowledge and not just become storehouses of facts. This idea is applicable to all forms of education, including engineering education.

Finally, the work of Thorndike has shown that knowledge is not easily transferred from one area of study to another unless the two areas have much in common. This research has been corroborated in my own experience. I have found that students have difficulty in applying the mathematics that they have learnt in their mathematics lectures to calculations in their engineering subjects. This means that engineering educators must be aware of this fact and integrate all aspects of the engineering curriculum thoroughly.

A number of the ideas of modern learning theory summarised in section 5.3.2 are not applicable to engineering education or the development of the engineering curriculum. Modern educators have shown the importance being sensitive to a student's cultural background for further learning. However, although cultural backgrounds cannot be ignored in engineering education they are not as significant as in many other fields of study because engineering theory is applicable and the same in all cultures. However, engineering educators must be sensitive to the fact that students from different cultures may approach their studies differently. For example, as mentioned in chapter 3, some cultures have a communal approach to learning whereas others have a more individual approach.

As section 5.3.2 mentions, modern education researchers have done important work on the influence of nature versus nurture and on IQ. It is unlikely that this work has much relevance for engineering education because once a student has decided to undertake engineering studies there is not much that can be done to influence his or her nature, or his or her IQ. All the educator can do is to provide a good learning environment for the student.

Finally, modern education researchers have shown that experts organise knowledge differently to neophytes. However, it is not clear how this organisation takes place or how it may be taught. Therefore, this fact is probably not useful for engineering education nor is it clear how it may be used in engineering education.

Understanding in Engineering Education

The summary in section 5.3.2 shows that an aspect of learning that all curriculum designers and educationalists agree on is that a major object of education is to enable students to construct a useful understanding of the topics being taught. *Understanding is one of the key aims of education.* This is obviously true in engineering education; however, the whole concept of understanding is difficult. Section 5.3.2 notes that Plato was puzzled by the concept of understanding, that there is no guaranteed way of ensuring that students understand a particular topic, that understanding can happen in unexpected ways and when it is not expected, and that understanding is difficult to assess particularly in the case of complex topics. It is much easier to assess a complete lack of understanding than to assess partial understanding. For example, in engineering it is hard to assess a student's understanding of complex numbers or of Laplace transforms because a student may be able to perform correct manipulations using these techniques without actually understanding what they are in any fundamental sense. I have found that this can result in the students incorrectly applying these techniques in certain situations without realising that they are doing so. However, one would think that because engineering is based on tried and tested 19th century mathematics and science it would be easier for students to construct understandings that are universally accepted. Unfortunately, as chapter one points out this is not the case because the failure rate among engineers is unacceptably high.

5.3.4.4 Analysis of Modern Theories of Teaching as Applied to Engineering Education

Modern teaching methods largely employ the methods and techniques that have been used historically. The methods, as discussed above in section 5.3.4.2 that apply to engineering education and the engineering curriculum, include the following:

- An educator must recognise the importance of a student's prior knowledge for any further learning and the fact that prior concepts are held strongly by students and are difficult to subsequently change. This in turn means that an educator must use analogies with extreme care because as I have found they can produce confused ideas when a topic is studied at a more advanced level.
- For good learning to take place the students must be interested and motivated.
- In order to teach an educator should try to create some form of cognitive conflict in the student's mind and encourage the student to look for ways of resolving the conflict to produce conceptual change.
- Educators should get students to predict the outcomes of practical exercises before they are undertaken and then explain any discrepancies between their predictions and the actual outcome. Whenever possible an educator should give the students practical exercises that have surprising outcomes.
- Because it is difficult to know what will trigger understanding in a student an educator should try to approach a new topic from as many perspectives as possible and if one approach does not seem to work a different one should be tried. This in turn means that an educator must have a sound subject knowledge in order to be able to do this. In addition, an educator must be able to adapt his or her approach to a topic to the content of that topic; again emphasising the importance of having sound subject knowledge.

A few teaching ideas and methods are unique to the current era and may be usefully used in engineering teaching. Modern technology has enabled educators to make use of still and moving images far more easily, and because learning is enhanced by images (see above) this technology should aid learning and teaching. Another idea that has been mooted, particularly in the university environment, is that of team teaching. Most engineering departments use this approach to a greater or lesser extent. For example, in first year engineering, Auckland University uses four different educators to lecture Engineering Systems. That is each engineering system is lectured by an educator who is an expert in that system.

Teaching methods that have a limited application to degree level engineering courses are the following. The maieutic approach is not really applicable to engineering teaching because the material in engineering courses does not leave room for discussion, as mentioned above. An exception to this is in tutorial sessions where it may be used in a simplified form to guide a student's understanding. The traditional apprenticeship approach to learning is not practical in degree level courses due to the large number of concepts that have to be learnt. The apprenticeship method would be far too time consuming and impractical. Teaching by rote should not be used by engineers because material learnt by rote is usually quickly forgotten. Instead engineers should endeavour to understand the material that they are learning and in order to remember it they should know the structure of the applicable engineering knowledge (see the discussion of memory above). That is, they should know the definitions of engineering terminology and jargon, the derivations of engineering formulas, and how these are used to solve problems; that is, using Wittgenstein's terminology; they must know the language game of engineering. Another modern approach to teaching that has limited application to engineering teaching is that of contrastive teaching. It is difficult to think of many engineering concepts that could be taught using contrasts and there does not appear to be any literature on using this approach in engineering.

An approach to modern teaching that has not been widely adopted in engineering is that of creating a free market for educators. This is virtually impossible in engineering because engineering qualifications are controlled by professional engineering bodies. That is, they accredit a limited number of institutions for awarding engineering degrees. Therefore, engineering educators must by employed by one of these institutions if they want to educate engineers. That is, engineering educators cannot privately educate engineers and award engineering qualifications without being accredited by the applicable professional body.

5.4 Engineering Curriculum Design

5.4.1 Summary of the Historical Ideas for Curriculum Design

5.4.1.1 Introduction and General Comments

The study of the ‘curriculum’ as a subject is relatively new. As chapter four shows, ancient thinkers tended to concentrated on the background studies necessary to educate oneself, that is, the trivium and quadrivium rather than setting up detailed curriculum for particular courses of study. Similarly, Goethe was of the view that one should learn logic and metaphysics before studying other topics.

In a general way Plato and Aristotle; and later Bacon, Harvey, Descartes and others; discussed the order of studies in many places; that is, they recommended starting by defining one’s terms and then move from the least difficult aspects of a topic to the more difficult. That is, knowledge must be broken down into small sections that may be easily dealt with and skills should be taught first and a general education second. Using a slightly different perspective Whitehead suggested that before studying the details of a topic one should have an overview of the topic so that one has some idea of where the studies are headed.

Chapter four continues by explaining that Hobbes and Rabelais were among the first to devise lists of topics, other than the trivium and the quadrivium, which should be studied by all educated people. However, apart from mathematics, philosophy, astronomy, and music, these lists do not have much in common.

In chapter four Adam Smith’s ideas are discussed. He points out that ancient Greek schooling was not centrally controlled or planned but adopted a laisser faire approach with each family using its own approach. He continues by noting that many centuries later traditional European universities stifled learning because they had set curricula which were fixated on the Christian religion which, due to its emphasis on belief and its intolerance of doubt, encouraged bad habits of thought. Hence few discoveries were made by people attached to universities and even researchers such as Newton did much of their original work outside the strictures of the university (Russell, 1950).

As mentioned in chapter four, Samuel Johnson adopted a different approach to the above thinkers in that he believed in regular study but not in a formal curriculum. He felt that one's studies should take one where they will and that one learns to express oneself by reading the best authors.

5.4.1.2 The Transferability of Learning

An aspect of curriculum design that has occupied thinkers from the time of the early Greeks is the concept of the transferability of learning. That is, the degree to which cognitive abilities acquired in one setting may be transferred to a different setting. If cognitive abilities are transferable then curriculum design is simplified; however, if they are not transferable then curriculum design becomes far more complex.

Chapter four explains that a number of ancient Greek thinkers, and more recently Descartes and Adam Smith, believed that the cognitive skills obtained in fundamental studies could be transferred to other areas of intellectual activity. Bacon took this idea one step further because he believed that cognitive abilities must be put into practice, that is, transferred to the practical world before they become useful. Thorndike, however, showed that knowledge is not easily transferable from one setting to another by students unless the two settings have much in common. Therefore, the transferability of knowledge is a fraught concept and curriculum designers must be aware of the difficulties involved. For example, students taught mathematics in a separate mathematics course may not be able to use the mathematics effectively in their engineering courses.

5.4.1.3 Curricula that Produce Knowledge, Understanding, and Creativity

After the transferability of knowledge the next fundamental aspect of curriculum design is that of creating a curriculum that enables students to construct knowledge and understanding, and to use the knowledge creatively.

Chapter four discusses the historical ideas involved in producing knowledge and understanding. Augustine, Descartes, and Hobbes emphasised the idea that a good fundamental knowledge is required for further studies and for understanding to develop. This chapter discusses Descartes ideas in some detail and many of these ideas may profitably be used in curriculum design. He noted that one acquires knowledge via intuitive understanding and memory, imagination, and via the senses; and he was of the opinion that mathematics was a good starting point for acquiring knowledge. Furthermore he believed that dialectic was useful for firming up knowledge but that it does not produce knowledge. Finally, Descartes believed that the reason one must be well versed in the steps of fundamental knowledge, for example one should know how engineering formulae are derived, was in order to see the structure of more complex problems. He recommended that once knowledge is understood it must be stated in its simplest terms. Chapter four notes that William James broadly agreed with Descartes except with the difference that James hypothesised that one initially senses things as a continuous whole and only later is able to break them down into their parts. That is, he reversed the process of how knowledge and understanding are gained, and believed that one really understands differences only when one analyses something into its parts.

5.4.1.4 Learning to Think

The next aspect of curriculum design that has been dealt with historically in some detail in chapter four is that of the techniques and methods of learning to think. This chapter points out that Plato used probing discussions, but with knowledgeable interlocutors who have good will, to encourage thinking. As mentioned above, Augustine believed that one should obtain an overall picture first and then go into the details of a topic. In addition he believed that a good memory as well a good general knowledge was important in all studies. Augustine also had the modern view that knowledge is knowledge because many authorities regard it as such, in other words, that knowledge is socially constructed.

Hobbes and Locke's views are also discussed in chapter four. Hobbes believed that experience is useful only for similar events but is useless for major departures from the ordinary, that is experience does not teach one to think but trains one like an animal. Locke concurred with Hobbes when he noted that the external world gives us ideas of the physical world and the mind gives understanding of these ideas. In addition he believed, like Descartes, that a mature thinker is a reflective thinker and that definitions are important for clear thinking. Locke was also of the view that basic axioms are useful for teaching and learning to think but that they do not help develop new knowledge. In addition, he believed that complex and simple ideas are understood in different ways: complex ideas are known before they are fully defined but simple ideas are the reverse.

Bacon wrote extensively on knowledge and education as chapter four explains. He felt that there are four 'arts' that are useful for learning to think; namely, inquiry/invention, examination/judgement, custody/memory, and elocution/tradition. In order to learn how to think Bacon recommended that one should know the rules of logic and rhetoric, and that knowledge of language and grammar were important. In conclusion, he noted that arguments may be demonstrated by using one or a combination of the following: consent of the senses, syllogism, induction, and congruity or agreement. In addition, he noted that the better one's general knowledge and fundamental principles are the more new knowledge one will be able to acquire and the more thorough one's investigation will be and the better one's thinking will be.

5.4.1.5 Summary of Curriculum Design in the Early 20^{th} C.

As detailed in chapter four, curriculum design in the first two thirds of the 20^{th} century came to be dominated by learning objectives. Curriculum researchers during this time tried to specify learning objectives in more and more meaningful ways. Initially three taxonomies of objectives were developed; namely the *cognitive*, the *affective*, and the *psychomotor* objectives. In addition, mastery learning was usually part of an outcomes based or objectives based education.

Chapter four continued by noting that various researchers further developed the idea of objectives. For example, Mager gave the requirements for well written objectives and Gronlund noted that objectives could not be applied to complex learning and therefore complex learning had to be broken down into smaller units before objectives could be specified. Tyler and Mager noted that objectives should be complete and specific. However, Eisner criticised Tyler and Mager by noting the following: much learning is not measurable and objectives will emphasise information over understanding; only trivial skills are capable of true mastery whereas higher level skills improve throughout one's life; objectives can be limiting for educators and students; objectives can hinder learning from diverse areas; and that cognitive abilities like creativity, insight, and integrity are not goal directed. Nevertheless, chapter four explains that curriculum design via learning objectives remained popular because it helps one to plan logical sequences for learning, it helps to provide ideas for class activities, and it helps to devise assessments. It also explains that learning objectives work best when students are aware of them and understand them clearly and that they seem to work better for average students on averagely difficult tasks.

However, chapter four makes the following concluding comments on traditional learning objectives. Although learning objectives can provide a guide for curriculum development, the disadvantages of using objectives to guide teaching are that educators tend to assess knowledge level objectives rather than higher learning and good students tend to find objectives constraining. Generally using learning objectives for higher level learning has not been successful because high level learning objectives are hard to define. Nevertheless an advantage of learning objectives is that they moved curriculum design from a content emphasis to an emphasis on students' learning.

A researcher who took learning objectives to a new level was Habermas. As detailed in chapter four, he claimed there are three different types of knowledge. The first type is mastering the environment using science and technology, the second type is developing a shared understanding using interpretation and hermeneutics, and the third type of knowledge is knowledge that produces freedom. This third type uses self-reflection and critical understanding. Mastery in the first type of knowledge may be attained by using objectives for curriculum design and conventional testing. Mastery in the second type is attained via group discussions and objectives that emphasise logical thought. Assessment for this type of learning tends to be subjective. The third type of knowledge is hard to specify and assess. Interestingly, chapter four notes that Lovat, et al. used these categories of knowledge for curriculum design.

In addition this chapter notes that Bligh has found that lectures and text are efficient methods for transmitting information, that is, for Habermas's first level of knowledge. However, conceptual change and intellectual development are difficult to achieve without undertaking study in small groups. Chapter four extends Bligh's ideas by discussing Säljö's theory on reproductive learning versus personal understanding. These two cognitive dimensions are expanded by Säljö as follows:

- Reproductive learning covers learning as acquiring knowledge, learning as memorising and the long term retention of facts, and learning as application: in particular, algorithmic application. These types of learning fall into Habermas's first level and are suited to a lecture presentation.
- Personal understanding covers learning as insight or understanding, that is the ability to use one's knowledge to interpret and understand new material; and learning as personal development, that is the ability to problem solve and to develop a personal philosophy. These types of learning fall into Habermas's second level and are suited to a small group study approach.

In conclusion, for objectives to be successful and therefore useful for curriculum design they must, according to chapter four, have the following characteristics:

- They must represent real goals, that is, the goals must not be trivial but should tell a student what they should be able to do differently as a result of their education.
- Learning objectives must place academic skills or personal learning in the context of the particular subject matter in hand. That is they should, for example, specify what is meant by critical thinking or communication skills in engineering.
- Learning objectives should include a description of the kind of performances by which achievement will be judged. That is, is it important that a student learn a particular skill or is the skill to be learnt in order to provide an indication of the student's level of understanding.
- Learning objectives should allow for either mastery or progress depending on the nature of the learning. That is, does the learning involve technical mastery or does it require the students to become more experienced in the processes which lead to a greater depth of understanding and creativity.
- Learning objectives should be memorable and limited in number so that students and educators can keep them in mind throughout the course.

5.4.2 A Summary of the Current Approaches to Curriculum Design

5.4.2.1 Introduction

In designing a modern curriculum a number of stakeholders must be considered such as the students, the community, industry, and the profession. As chapter four details Toohey regards the central questions in curriculum design to be: (a) What is important for students to know? (b) What is the best way for them to learn it? She highlights the following subsidiary questions resulting from these questions:

- What is it that characterises knowledge in the profession being studied?

- How does learning occur and how is it best facilitated?
- What goals and objectives are worthwhile, and how are they best expressed in order to promote the type of learning aimed for?
- What content must be included, how should it be organised, and what might be left for students to learn in other ways?
- What is the role of assessment and what forms should it take?
- What resources and infrastructure will be needed to achieve the above?
- Who else has a legitimate interest in this curriculum? (For example, what is the relationship between the faculty and professional associations, the funding bodies, and the university itself?)
- What prior knowledge do students have and what sort of diagnostic testing will make this knowledge known to the curriculum designer?

In summary, curriculum design should be a top down process that determines the overall program goals which then determine the course goals, the learning experiences, and the teaching plans. Therefore, although students are responsible for their own learning, the overall program goals and aims must be clearly specified.

The ultimate aim of the above questions is to ensure that the curriculum goals are clear to all involved. In addition, curriculum designers must be aware of their own beliefs and biases about education in order to reduce any untoward effects that these factors may have on the design of the curriculum.

As chapter four details many organisations have produced detailed curricula for engineers and in addition this chapter lists a number of researchers such as Harvey, Bowden, and Malpas that have surveyed academics, recruiters, and employers to determine the types of knowledge and skills that engineers need to have. Harvey found that the key attributes of engineers that the above stakeholders viewed as important were the ability to communicate, the ability to solve problems, analytical and mathematical skills, the ability to work in teams, flexibility, judgement, and enquiry skills. Harvey also found that all the stakeholders viewed core engineering knowledge as important. Bowden found that engineering curricula must integrate knowledge and generic capabilities.

Chapter four explains that Malpas provided a possible basis for curriculum design in engineering. He defined *engineering knowledge* as the growing body of facts, experience, and skills as well as an understanding of the fields of application of this knowledge and the *engineering process* as the creative process, which applies knowledge and experience to develop solutions to meet a requirement as well as informed judgement to implement the best solution. The conclusions that may be drawn from this chapter are that graduates must be able to do things and not just have knowledge; that is, learning knowledge is a means not an end in engineering.

In conclusion, it is worth noting that many factors can make the design of a curriculum less than ideal. For example, in chapter four, Bowden points out an important problem for curriculum designers. The problem is that not everything that a future engineer may need can be specified in an engineering curriculum because the future developments in engineering are unknown.

5.4.2.2 Curriculum Design Philosophies

Although most curricula are a combination of one or more design philosophies the main types of curriculum design, detailed in chapter four, are summarised below.

The Traditional or Discipline Based Approach

In this approach the course follows structure of the knowledge in the discipline and the topics are logically structured. The curriculum therefore becomes a logically structured list of important topics for students to learn and the content is chosen for breadth so students get an overview of the field. Assessments are used to confirm the students' knowledge and to rank them using norm referencing.

In this approach knowledge exists independently of social structures and is abstract, that is knowledge is used to control one's environment and not for personal expression. Important knowledge is transmitted to the students and it is assumed that students are motivated, diligent, and can memorise.

An advantage of this method is that it allows large classes to be taught using, usually, a lecture type environment and printed notes. Tutorials and labs are done in small groups with postgraduate students as tutors. A drawback with this method is that it is not related to how students learn, their interests, or their daily life.

The Performance Based Approach

In this approach, curriculum designers produce clearly defined objectives expressed in behavioural terms so that they can be assessed. Curriculum design is therefore a three-phase process of establishing precise and useful objectives, planning study methods, and assessing whether the students have achieved the objectives. A student's understanding is shown by what they can do and the aim of learning is to expand the range of what they can do. That is, frequent criteria based assessments are used. There is, therefore, no dichotomy between theoretical and applied knowledge.

In the performance based approach to curriculum design learning tasks are broken down into their components so that learning is a step-by-step increase of knowledge. An advantage of this step-by-step method is that it is often suited to computer based instruction or distance learning. However in many courses laboratories are needed to practice skills which can make the logistics of distance learning difficult.

A disadvantage of this approach is that the students have no say in what they learn because course content is usually chosen by an analysis of the requirements of a profession. In addition, this approach often ignores the values and ethics applicable to a particular profession or field of study.

The Cognitive Approach

The cognitive approach adopts the view that a tertiary education should develop students' minds and teach them how to learn. In order for learning to take place, according to this approach, expert educators must guide neophytes and, because rigorous thinking and analysis are not innate, they must be developed in the students. In addition, chapter four discussed Posner's view on learning that people construct ideas and meaning based on innate structures for knowledge, their sensory input, and their existing ideas and experience. This implies that the cognitive approach to curriculum design and constructivist theory are closely allied. However, for constructed knowledge to be useful, in the engineering sense, it must be based on a consilience of inductions; that is, radical relativism does not make sense for the hard sciences and engineering.

A course based on the cognitive approach consists of a limited amount of material but this is then covered in depth. In order to do this small group work is necessary and the role of the educator is to point out inconsistencies in the knowledge of the students. The aim of a course structured in this way is for students to learn to think critically, become life-long learners, and to be able to solve problems. This approach requires extensive resources in educators and libraries, and is therefore hard to adopt for distance learning.

Assessments using this approach are performance tasks in which the students can show their thinking skills. These assessments are, therefore, hard to mark because they tend to be subjective.

However it is important to note that, as chapter three pointed out, Thorndike showed that cognitive transfer is fairly limited and seems to take place only in related cognitive domains. In other words, an attempt to teach students to think in a general non-specific way may not be successful.

Personal Relevance Approach

In this approach the learners are consulted during the design of the curriculum and the curriculum is made relevant to the student's life. This approach is, therefore, suited to mature learners.

The Socially Critical Approach

This method of curriculum design develops a student's critical abilities so that they develop an awareness of the ills of society and are motivated to change them. The underlying assumption of this approach is that society is moulded by elite groups and that traditional education aims to maintain and support these groups. That is, the socially and economically powerful influence traditional curricula. Therefore the socially critical approach is designed to reveal the hidden values that a society is based upon; that is, knowledge is constructed in historical, cultural, and social frameworks.

In this approach educators point out the origins of values and challenge the students' preconceptions. In particular they encourage the students to continually ask the question: 'Whose interests are served here?' The aim of this method of curriculum design is to enable students to develop and defend arguments in a social context and not as individuals. Course assessment is usually via collaborative projects and peer assessment; that is, there is extensive student input into assessments.

A disadvantage of this approach is that it is expensive to run because it can be successfully carried out only in small groups.

5.4.2.3 Designing a Curriculum

In order to practically design a curriculum, that is, in order to determine the curriculum content, chapter four suggests that the following methods may be adopted; either on their own or in combination:

- Use, as a guide, what a master performer in the field needs.
- Use concept maps.
- Perform a professional functional analysis.

Once the content of the curriculum has been determined this content has to be structured in a formal way to create the curriculum. The ways that content may be structure are obviously related to the types of curriculum mentioned above but usually include a hybrid of the following structures.

A Logical Structure

In this structure the curriculum content is arranged according to the subject matter. This structure is generally regarded as the traditional method of arranging curricula.

A Competency Based Structure

In a competency based structure the course is arranged according to the performances required from students. The structure is ordered taking the psychological needs of students into account, for example, prerequisite skills must be identified first. This structure makes for motivated students because they can see the relevance of the course. A disadvantage of this structure is that these courses are generally not flexible and can produce a weak discipline knowledge compared to the logical structure.

A Problem Based Structure

In this structure the course is entirely based on problems; that is, problems are not just used to aid teaching but are used to decide what needs to be learnt. Difficulties with this structure are that it is difficult to choose informative learning problems and the students may not develop a well structured knowledge base. However, as mentioned in chapter four there is some evidence that this structure improves a student's ability to apply knowledge.

Usually students enjoy this approach, develop a good understanding of the topics covered, are more motivated, and integrate theory and practice better. However, less theory is covered and, as mentioned above, general principles are not as well learnt as in the more traditional methods. In addition, some academic staff may find this approach difficult to implement.

The Cognitive Structure

In this structure the course is organised around key concepts; for example, around power generation in electrical engineering or around critical thinking in the humanities. The aim of this structure is to enable the students to practise the important ideas and ways of thinking in a discipline. A disadvantage of this structure is that the students do not get as good a ‘map’ of the subject or of the origins of concepts as in more traditional approaches. A difficulty with this structure is that it needs educators who are good at controlling group work.

5.4.2.4 General Comments

This section concludes the summary on curriculum design by giving some general comments on curricula and on the influence of curricula on teaching, learning, and assessment.

The curriculum design influences the teaching and learning that takes place because the teaching strategy in a curriculum is obviously a plan for someone else’s learning. Chapter four discusses Biggs’ factors for learning and points out that the curriculum is one of these factors. Bigg’s factors that influence learning are the students’ prior knowledge, their IQ, their personality, their background and motivation, the nature of subject, the course structure, the teaching strategy, the time available, and the type of assessment. However, it is hard to specify an optimum strategy for learning, and selecting a teaching strategy becomes more an art than science. In tertiary teaching, as Toohey points out in this chapter, often a student’s prior knowledge is unknown; the teaching sequence is wrong, for example the laboratory work is done before the relevant lecture is given; the educators are not good at group work; and feedback from the students is not good because lectures are overcrowded.

Chapter four continues by explaining that questioning, team work, and getting students to teach other students can be advantageous for improving understanding. For example, post-graduate students could run tutorial sessions. In addition, students must have many opportunities to practice new skills and knowledge and must be given opportunities to transfer skills from one discipline to another. That is, the curriculum must provide supportive opportunities for this to take place because, as mentioned above, the transfer of knowledge from one setting to another is not automatic.

However as chapter four points out it is often the assessment method that determines the learning that takes place. In order to assess the material covered in a curriculum two types of assessment methods are widely used: norm referenced or criteria referenced assessments. Chapter four explains that, these two methods are not that different because norm referenced assessments are often used to set up criteria based assessments. However, in norm referenced assessments the assessment criteria are usually not as clearly defined as in criteria based systems. Therefore, this chapter suggests that the best approach to assessment would be to use different assessments for each of Habermas's areas of knowledge. That is, technical knowledge would be assessed via conventional types of tests. However, communication types of knowledge and reflective knowledge are difficult to assess.

Finally, chapter four mentions Mentkowski's ideas on assessment. First, he notes that expanding the outcomes of curricula to include not only what students *know* but also what they are able to *do* has led to the development of alternative assessments such as performance and portfolio assessment. Second, expanding learning to include active collaboration with others and to more reflective and self-sustained learning has led to the assessment of projects produced by groups of students and to more attention being paid to self assessment. Third, expanding educational goals to include personal growth has led to the assessment of broad developmental patterns over time.

5.4.3 An Analysis of Curriculum Design as Applied to Engineering Education

5.4.3.1 Analysis of Historical Curriculum Design as Applied to Engineering Education

As discussed above, Plato, Aristotle, St. Augustine, the concept of the trivium and quadrivium, Descartes, Bacon, and Hobbes all placed great emphasis on the students having the basic tools and fundamental knowledge for undertaking self education. These ideas can be profitably applied to the design of the engineering curriculum. Therefore, the engineering curriculum content should include a significant amount of fundamental material which engineers can use for further self education; that is, material which is unlikely to become obsolete in the near future. In general this material will include, but not be limited to, engineering mathematics and logic; the basic science upon which engineering is based; and the methods, techniques, and technology required to apply this knowledge.

In addition, many of the above thinkers emphasised that a course of study, for example the engineering curriculum, should start from first principles and then move onto more complex material. Closely linked to this graded approach is the requirement that curriculum designers have a clear knowledge of the students prior knowledge so that they can determine the level at which the curriculum should start. This may require the students to sit focused diagnostic assessments before being allowed to undertake a particular course of tertiary study. In other words, the curriculum content must be closely matched to the students' knowledge and abilities.

As the history of curriculum design, summarised above, points out it is necessary for a curriculum designer to have a clear overall view of the objectives of a course of study. Without this clear view it will be difficult for a curriculum designer to devise a coherent course. It is also clear that many of the above thinkers strongly believed the personal experience and experimentation are important parts of the learning process. Therefore, it is important that the engineering curriculum include provision for the students to obtain this practical experience. However, as Hobbes pointed out, the theory underlying the experience must be well understood because experience on its own is not helpful in new situations. That is, experience is helpful only in similar situations and does not necessarily teach one to think but only to memorise these situations.

Finally, a much debated historical aspect of designing a course of study is that of the transferability of knowledge. As mentioned above, Thorndike showed that the transfer of knowledge does not take place easily unless the areas in which the transfer is to take place have much in common. The implication of this for engineering education is that the various aspects of engineering knowledge in the curriculum should be smoothly integrated and not treated as separate subjects so that the students see the whole structure as engineering studies and not as separate independent subjects. In addition, this integration of subject matter can be further promoted by students being required to undertake substantial projects: either individually or in groups.

5.4.3.2 Analysis of 20th Century Curriculum Design as Applied to Engineering Education

As summarised above, the major development in curriculum design that took place in the later part of the 20th century was that of setting learning objectives. Due to the definite nature of engineering knowledge, as discussed above, engineering curricula are well suited to being expressed in terms of objectives that have to be met. That is, most of engineering knowledge involves mastering the environment using science and technology which falls into Habermas's first level of cognitive understanding; a level that may be profitably expressed in terms of learning objectives. However, the major disadvantage of objectives is that they allow one to fall easily into the trap of emphasising knowledge over understanding. This is a trap that must be avoided by engineering curriculum designers because it is essential that engineers understand engineering knowledge so that they can continue to educate themselves over their 45 year working career. In addition, learning objectives may be constraining for talented students so curriculum designers must be aware of this and allow for these students to go beyond the basic objectives set out in the curriculum. This may be done, for example, via student projects. Finally, the list of requirements for learning objectives to be successful, given in section 5.4.1.5 above, must be kept in mind by curriculum designers as they develop the objectives for an engineering curriculum.

5.4.3.3 Analysis of Current Curriculum Design as Applied to Engineering Education

The summary in section 5.4.2.1 above lists the requirements for an engineering curriculum as specified by the professional engineering bodies, industry, and as seen by experienced academics. In brief, these requirements are that engineers must be able to do the following: mathematical analysis, understand the core engineering knowledge, solve problems, communicate, be flexible, work in teams, use judgement, and undertake self education over their 45 year working career. That is, the ultimate objective of an engineering curriculum is that engineers have a good understanding of engineering theory and technology, and be able to apply them creatively.

As far as the actual curriculum philosophy is concerned only the first two of Toohey's approaches to curriculum design, summarised above, are applicable. Her last three approaches; the cognitive approach, the personal relevance approach, and the socially critical approach; are not applicable to engineering curricula because engineering knowledge does not leave much room for discussion and these three approaches to curriculum design are suitable for topics that involve discussion or debate in a small group setting. In addition, these approaches are used for topics that involve a limited amount of material that is covered in great depth. Engineering knowledge does not fit this specification at all because engineering consists of a large number of concepts that have to be covered in a limited time.

Toohey's first two approaches, the discipline based approach and the performance based approach summarised in section 5.4.2.2, can be profitably used to develop an engineering curriculum because they are suited to studies involving knowledge that has been tried, tested, and settled; that is, knowledge that is not open for discussion and debate, and knowledge that is not closely related to the students' day to day lives. The first approach, a discipline based curriculum, structures knowledge logically covering a broad range of concepts and is suitable for knowledge that is used to control the environment: that is, engineering. In this approach to curriculum design settled knowledge is transmitted to large groups of students in a lecture environment. The students' knowledge is then consolidated and their understanding tested and developed in tutorial sessions and in practical laboratory exercises. That is, the students are required to construct a system of engineering understanding that parallels as closely as possible the understanding of professional practicing engineers. The students are not required to construct new understandings or unique understandings. The problems with this approach are that the students may be tempted to merely memorise knowledge rather than understand it and the logical structure of the discipline may not be related to how students learn. Therefore the engineering curriculum should be a hybrid structure that also makes use of Toohey's second approach to curriculum design, namely, the performance based approach.

The performance based approach has many overlaps with the discipline based approach. In this approach a list of objectives is produced which specifies what the students must be able to do and how they are to be assessed. These objectives are usually based on the logical structure of the discipline but take into account how the students learn, that is, a step by step increase in knowledge is used for developing the curriculum. Usually assessments are criteria based. However, as Toohey noted above, the assessment criteria are usually based on the norm based assessments that are often used in the above discipline based approach. That is the criteria based assessments and the norm based assessment are often not fundamentally different in practice. The disadvantages of this approach are that the students have no say in the development of the curriculum, and that discussions of values and ethics are not usually undertaken. Neither of these two disadvantages is a problem for engineering curricula because, first, undergraduate students do not have the engineering knowledge to contribute to the development of an engineering curriculum and, second, engineering knowledge is ethically neutral. It is the application of engineering knowledge which involves ethical issues and in a democratic society these considerations are the responsibility of elected representatives of society: not engineers.

As the summary given in section 5.4.2.3 points out there are various methods that may be used to practically design a curriculum. For engineering it is clear that a professional functional analysis would be the most effective way to get a list of topics that need to be included in the curriculum. These topics would then be arranged in a graded logical structure, taking into account the students prior knowledge, so that a competency based approach to the teaching and assessment of the material can be adopted. It is unlikely that, for example, a socially critical approach which analyses power structures or the cognitive approach which concentrates on teaching students to think generally would be useful for designing an engineering curriculum. This is because it is clear that engineering fundamentals are not greatly influenced by the power structures in society and engineers have to learn many scientific and mathematical concepts as well as learning to think in a fairly narrow circumscribed way.

The goal of the engineering curriculum is, therefore, to enable the students to construct an understanding of engineering concepts (based mostly on 19^{th} century mathematics and science) and to apply this understanding and modern technology in creative ways. From the above discussion it is clear that the practical results of using these two approaches for curriculum design will be the following:

- The content of the curriculum will be a set of objectives that concentrates on the fundamentals of engineering knowledge, that is, knowledge that has a long half-life. However, for good learning to take place the students' interest must be maintained so the approach to this fundamental knowledge must be such that it holds the students interest and keeps them motivated.
- Knowledge will be transferred to large groups of students via lectures, using still and moving images, and text books. Problem based teaching may be used on some aspects of the course but, due to time constraints and the number of new concepts to be covered, not for the whole course; for example, some laboratory exercises could be structured as problems for students to solve.

- Small group tutorials run by graduate students will be used to consolidate and refine the students' construction of their understanding of the engineering concepts.
- Laboratories will be used to refine and consolidate the students' construction of their understanding of engineering concepts and give the students practice in using modern technology. They will not be used to try to simulate what happens in industry.
- Assessments will be used to diagnose the students learning, that is, to determine whether they have achieved the objectives set out in the curriculum. Assessments will be at both the subject level and at the course level in order to determine whether the individual subject objectives have been met and whether the overall objects of the course have been met. Course objectives could be assessed, for example, by requiring the students to do global projects either individually or in groups. As noted above Habermas pointed out that technical material can be reliably assessed using conventional assessment techniques such as tests and examinations.
- The resources required for the implementation of the curriculum will include large lecture facilities equipped with the latest image production equipment and laboratories equipped with technology that can be used to consolidate a student's construction of engineering understanding. Small group tutorial rooms will also be required.
- The stakeholders in the engineering curriculum will include the students, the professional institutes, the technical institutes, the engineering industry, and the tertiary educational organisations.

5.5 Final Conclusions

5.5.1 Introduction

As explained in chapter one this study was undertaken because the success rate for electrical engineering undergraduates has been historically low. Currently the Manukau Institute of Technology has a desired pass rate for its four year electrical engineering degree of 13.3 % (a 75 % pass rate each semester) with a future aim of 21 % (a 90 % pass rate each semester) by 2012 (Quigg, 2008). That is, currently, the requirement is that 13.3 % of the students that start the four year degree shall complete the degree in four years with the target four year completion rate rising to 21% by 2012. This situation should not be accepted particularly since the New Zealand tax payer funds approximately 60 % of the cost of tertiary courses (Profile and Trends, 2006). In addition, the teaching of mathematics has been shown above, by a number of sources, to have not improved during the 20th century. Now because engineering is fundamentally based on mathematics these two problems are probably related. It is also worth noting that although the above chapters have dealt with electrical engineering specifically similar problems occur across all the engineering disciplines. The reason for this is that the first and second years of all the engineering curricula (except for civil engineering) are common at most educational institutions thereby producing similar problems in all these disciplines (see, for example, UoA, 2003).

Ideally, at least 50 % of the students that start a four year engineering degree should finish it in four years, that is, the average student should be able to finish a four year degree in four years. If an average student cannot finish a four year degree in four years then it cannot be regarded as a four year degree, that is, it is in reality a five or six year degree. In fact, it could be argued that twice as many students should be able to finish a four year degree in four years as not. That is, instead of requiring a success rate of 50 % a success rate of 67 % is what is required. Whichever rate is chosen it is much higher than the current 13.3 % Manukau Institute of Technology target.

Therefore, as mentioned in chapter one the main research question that this study investigated was why the engineering completion rate is so low? Using all the information set out in this chapter I am now in a position to analyse this question. The following sections each examine a particular aspect of this problem.

5.5.2 The Nature of an Engineering Education

Chapter two is an important chapter because it puts an engineering education in perspective; that is, it compares an engineering education with what educationalists over the centuries have regarded as a true education. What this analysis shows is that engineering studies cannot be considered as an education in the true sense - no matter which definition of a true education one adopts (see table 2.1). This has a number of implications as follows.

First, I have found from personal experience, both while a student and as an engineering educator, that first year engineering students are unaware of the fact that engineering studies are not a true education but are purely vocational studies that will enable them to perform a narrow range of work related functions. Engineering, as against the products of engineering, has little relevance for day to day life. The result of this is that many engineers become disillusioned with engineering studies which may affect their motivation and hence their success rate. It should be made clear to first year engineers what exactly engineering studies are and the fact that once they have completed their engineering studies they will still have to obtain a general education via self study or via liberal arts courses in tertiary institutions.

5.5.3 Teaching and Learning in Engineering

Since engineering is based on 19^{th} century mathematics and science the approach to the teaching and learning of engineering can be the traditional one of lectures, tutorials, laboratories, and projects. That is, the high failure rate in engineering is unlikely to be due to the approach adopted for the teaching and learning in engineering.

5.5.4 The Engineering Curriculum

Since engineering studies fall into Habermas's first level of cognitive abilities, namely controlling nature, they can be arranged in a standard competency based curriculum as discussed above. However, a major flaw in the structure of the engineering curricula is that they are not student centred in any way. If chapter four and the summary in chapter five are examined it is clear that at no stage has the student been considered in the development of the curriculum. Chapter four details how the professional bodies, the technical bodies, industry, and academia are all consulted regarding what goes into a curriculum. However, I was not able to find any research that investigated what an average student *could achieve* in four years. A number of research studies have been undertaken which ask students what they think of a particular curriculum of engineering studies: which is not the same thing. However, no research has tried to determine what a student can actually achieve in four years. That is, how much material can be put into a curriculum with the expectation that an average student will be able to complete the curriculum in four years? Based on the high failure rate of engineering students detailed in chapter one it seems clear then that the amount of material in the typical engineering curriculum needs to be related to the ability of the average student; something that is not currently attempted in any way by any institution that I have examined. In reality it is irrelevant what industry, or the professional bodies, or academia feels should be in the engineering curriculum. The only real measure is how much material the average student can successfully deal with in four years. If this material is not sufficient for industry then the length of the engineering course must be increased or some other solution sort but cramming the curriculum with more material than a student can deal with is pointless and demotivating for the students.

It is therefore imperative that research be undertaken to determine what the average student can deal with in four years. This research will be difficult and time consuming and could form the topic for a complete research thesis. As an example, the following is a brief analysis of a typical electrical engineering degree course which has the problems mentioned above.

5.5.4.1 Analysis of a Typical Electrical Engineering Course

Power Systems 2 (525.704) is a typical senior level electrical engineering course (Manukau Institute of Technology, 2009). An examination of the curriculum for this course illustrates all the problems listed above. First, this examination will show that there is no evidence that student abilities were considered in the development of this course (a fact I can confirm personally because I was a member of the development committee). Second, the amount of material to be covered in one semester is enormous and covers a wide range of engineering concepts: from the analysis of power lines using partial differential equations and hyperbolic functions, to power flows in large networks, to the operation and control of the New Zealand grid. Third, this course also requires that the students develop a number of generic abilities, for example, high ethical standards. As discussed above these types of aims should not be included in engineering courses because they can not be effectively covered while trying to cover fundamental engineering concepts at the same time. That is, engineering courses should concentrate on engineering and leave topics such as ethics, economics, etc to post-graduate studies.

Future curriculum developers should reform the content of courses such as Power Systems 2 in line with the comments in this chapter in order to improve their pedagogical effectiveness and thereby reduce the high failure rate of electrical engineering students.

5.5.5 Wittgenstein and the Paradox of Understanding

5.5.5.1 Introduction

As chapter four explains engineering curricula emphasise the ideas that students must understand the material covered and be able to use the material in creative ways. This section discusses the concept of understanding, and to a lesser degree creativity, and from this discussion draws implications for the engineering curriculum, and for teaching and learning in engineering. However, as this section will show, *understanding* is not well understood and this, together with the discussion in section 5.5.4 above, is a possible reason why the failure rate in engineering is so high.

5.5.5.2 Understanding

Mathematics, science, and engineering have been taught in various forms for centuries. However, as this thesis has pointed out educators have had limited success in developing mathematical and engineering understanding in their students. In addition, this thesis has pointed out that over the last few decades, the level of mathematics' understanding has dropped in the western world. If educators have not been able to develop a sure method of producing understanding in students, educators must be missing something fundamental about the nature of *understanding*. ***There must be something intrinsic to* understanding *that is not understood!***

A perusal of the ERIC database and education journal indices will show that there are many papers and books on *understanding mathematics*, or *understanding physics*, or *understanding science*, etc, etc (for example, see Sierpinska, 1994). However, this same perusal will also show that there is almost no literature on understanding *understanding*. This is puzzling since one of the main aims of teaching, and engineering curricula in particular, is to inculcate understanding in students. Plato, Locke, Hume, mentioned above, as well as Kant (1990a, 1990d), Ryle (1949), Pinker (1999), Sternberg (1995), and Penrose (1999) recognise that the concept of understanding is puzzling but do not try to explain it.

One of the few thinkers that has investigated this problem is Ludwig Wittgenstein (1958) in sections 138-42, 151-5,179-84, 191-7 of his Philosophical Investigations. The key insight that Wittgenstein illustrates in these sections is that understanding is not a process but a ***sudden event***. We have all experienced the phenomenon of not being able to understand something, for example an unfamiliar piece of mathematics, however after mulling over it for a while it suddenly, instantly becomes clear. This experience shows that this is usually not a step-by-step process but a sudden coup du ciel. What causes this sudden insight is not clear and few thinkers, apart from Wittgenstein, appear to have examined it. Mason (2003) in his interesting text *Understanding Understanding* does investigate *understanding* but does not try to explain this event neither does Ziff (1972). Wittgenstein pointed out that the confusion between thinking of understanding as a *process* and understanding as an *event* is due to the way in which one talks about understanding. One tends to think of understanding as a well understood process: almost as something concrete rather than a mental state that suddenly arises.

A further facet of this problem is that once we feel we have understood something, such as an unfamiliar piece of mathematics, what is it that justifies us in saying, “Now I understand!”? It is possible that understanding is part of a set of difficult philosophical problems, identified by McGinn (discussed in Pinker, 1999), such as consciousness, free will, and creativity which may be intractable.

5.5.5.3 Implications

The fact that humankind does not understand what takes place when someone suddenly understands something produces a number of implications for education in general and engineering education in particular; such as the following:

Research into Understanding

It is imperative that research should be carried out into this phenomenon. Firstly to try to determine whether understanding *understanding* is a tractable problem or not; and secondly, if it is a tractable problem, to try to understand the phenomenon and what promotes it and what hinders it. Because so little is known about *understanding* and how it suddenly occurs, it is difficult to elaborate here on the research program suggested.

Working around the Problem

Although one does not currently understand the phenomenon of *understanding* it is obviously necessary for education to continue without this understanding. Therefore, although *understanding* is not understood, a number of activities may encourage it. If the event of *understanding* is similar to sudden creative insight the conditions and environment that encourage creativity may help to develop *understanding*. However, most of what is about to follow is speculative and is not supported by research.

Teaching to Promote Understanding

Inspired by Sternberg's (1995) list of factors that promote creativity one may, assuming *understanding* and *creativity* are analogous phenomena, make the following hypotheses:

First, having well qualified educators that understand their subjects in great depth probably helps. It was noted in section 3.2.3 that Weber pointed out that there is a tension between research and teaching in modern universities. Educators are not necessarily good researchers and vice versa. In addition, research results in narrow specialisations. Therefore, all university educators should undertake pedagogical studies as well as having good subject knowledge. This is necessary because educators who have an in depth knowledge of their subjects can approach the concepts in their subjects from many different, unique perspectives. One of these perspectives may then trigger *understanding* in a student and the larger the number of ‘methods of attack’ that an educator can use the greater is the chance that one of them will act as a trigger.

Second, a supportive environment will probably aid *understanding*. This may be because if an educator understands that he or she does not know what exactly is going to trigger *understanding* the educator will realise that it is necessary to be patient and supportive until the event of *understanding* occurs due to the various approaches adopted. In addition, a supportive environment will encourage students to try different solutions to problems and to use innovative means to develop *understanding*.

Third, it seems reasonable that a student must be well motivated and interested to achieve *understanding* of the material being taught. Without this motivation it is unlikely that the student will mull over the problem for an extended period of time and try various solutions. Therefore it is necessary for the educator to clearly justify why it is necessary that a particular piece of knowledge is important and must be understood so that the study itself becomes intrinsically motivating. That is, the student must be convinced that *understanding* the work is important.

Fourth, as with creativity, the more prior knowledge, skills, and techniques that a student has in a particular area the more likely it appears that a student will be able extend his or her *understanding* in that area. One implication that follows from this point is that rote learning, memorising, and learning derivations should not be discouraged because it is possible that a piece of knowledge learnt by rote may trigger the *understanding* of something more complex. In addition, the new *understandings* that an educator is trying to produce in a student must be carefully chosen so that they build gradually on the students’ prior knowledge and skills. This in turn implies that educators must have an in-depth knowledge of their students’ current level of *understanding*.

Fifth, *understanding* seems to be enhanced in situations where there is social interaction. That is, to understand one must use and discuss knowledge. This point follows from one possible interpretation of Wittgenstein's idea that *private languages* are not possible and that much social interaction involves understanding how a *language game* is 'played' in a particular situation (Wittgenstein, 1958). For example, in mathematics a large amount of technical jargon must be known before any real *understanding* can be developed, that is one must be able to 'play' the language game of mathematics in order to understand mathematics.

Finally, in order to understand a difficult topic (and to produce creative solutions to problems) periods of hard work followed by periods of total rest seem to be advantageous.

As Sternberg points out, there is some consensus that the above points encourage creativity but he adds that many psychologists dispute one or more of these points. However, it does not appear as though any research has been carried out to determine whether any of the above consistently encourages the development of *understanding*.

Assessment

If it is difficult to determine whether someone has understood something then it will be difficult to make an accurate assessment of a student's prior knowledge. This makes the development of an engineering curriculum difficult because, as has been mentioned many times above, all new learning has to be based on the students' prior knowledge. This lack of a good knowledge of a student's prior knowledge could be one of the factors contributing to the high failure rate in engineering: particularly in the first year.

This assessment problem continues throughout the engineering program. Often assessments, particularly in engineering, indicate when some concept has *not been understood* rather than to what degree concepts have been understood. That is, it is difficult, in a limited time, to determine how well a student has understood all the ramifications of a particular concept but it is usually clear when a student has not understood a concept (Mason, 2003).

If one does not understand *understanding* fair and meaningful assessment becomes difficult. For example, in a mathematics assessment, it is possible to set standard problems that the students have done previously. Obviously this would not assess the students' *understanding* because they may have merely learnt the problems by rote or, at best, have learnt the *pattern* of the problem by rote and not fundamentally understand what they are doing. In addition, a one-off two or three hour assessment, by its fundamental nature, can assess only a subset of a semesters work so that the students' overall *understanding* of the semester's work will not have been assessed.

An alternative is to set problems in the assessments that the students have not seen before and that cannot be solved by just memorising solutions or patterns of solutions; that is, problems that require a good *understanding* of the work to complete. The difficulty with this approach is that even good students with a good *understanding* of the work may not, in the limited time of the assessment, have the sudden insight required to solve some of the problems. This is then likely to prove to be demotivating and damage a student's confidence with mathematics. Hence the common lament heard from students that they do not like mathematics because it is too hard! In addition, neither of the above two methods of assessment will assess meta-*understanding*; that is, they will not assess whether the student really understands what the knowledge is used for or its range of applications.

A second alternative is to use a portfolio of work to assess the students' *understanding*. This method has a number of advantages and will probably be a more effective measure than more traditional examination type assessments (Arter & Spandel, 1992). However, again there does not appear to be much, if any, research into whether portfolios truly assess *understanding* or not. This is possibly because it is difficult to measure *understanding* in an independent unbiased way in order to carry out the research. A further difficulty with portfolios is their administration. It is difficult to keep track of the students' portfolios during a semester and to ensure that all the work in the portfolio is that of a particular student and is not plagiarised (Arter & Spandel, 1992).

5.5.5.4 Conclusions

Section 5.5.5 has highlighted the problem of *understanding*, that is, that it is a sudden event and it is not understood how to consistently cause this event to occur. The result of this is that teaching and assessment become difficult. This section has also made some tentative suggestions about how educators can work around this problem in day-to-day teaching and in assessment. However, much more research into this problem is required.

An additional complication pointed out by Mason (2003) is that there are many types of *understandings* so this problem extends beyond the fields of mathematics, science, and engineering to all facets of education. It is just that in mathematics and science the problem of *understanding* is highlighted due to the nature of the topics. That is, with most mathematics problems a student has a flash of insight and solves the problem or does not. This contrast is not so obvious in many other subjects, for example, in writing English essays in which a student may pass with a limited *understanding* of the topic and not much creative insight. (This comment should not be taken as a disparagement of essay writing. A well written essay requires as much *understanding* and creative insight as any other form of intellectual activity.)

In the same way that there are many types of *understanding* there are also many ways of *understanding*. For example, Olivier Messiaen claimed to understand musical harmony in terms of colour and the mathematician, Ramanujan, is reputed to have understood numbers in terms of feelings (Mason, 2003).

A further complication mentioned by Sternberg (1995) is that in creativity, and presumably in developing *understanding*, a certain amount of subconscious processing seems to take place before the creative event occurs. Again, this processing is little understood and is hard to examine and measure (creativity, 2006).

This lack of understanding of *understanding* further complicates the problem of establishing an engineering curriculum because it is not clear what amount of material an average student can understand in four years if the whole concept of *understanding* is not understood. In addition it is difficult to say categorically how engineering should be taught or what theories of learning should be applied to engineering studies if it is not understood how *understanding* occurs. Possibly the single most important recommendation that can be made is that a research program is set up to determine, if possible, what amount of material (the number of new concepts) an average engineering student can understand in four years. That is, the engineering curriculum must become student centred. It may not be possible to determine, in an analytical way, how much material an average student can handle in four years so this may have to be determined by trial and error, that is, empirically.

A second recommendation that can be made is that engineering educators must be well qualified engineers but also well qualified educators. If an educator is aware of this problem of *understanding* and knows his or her topic well, as well as being highly qualified as an educator, then he or she can try various approaches to teaching in order to try to trigger *understanding*. However, if an educator does not have good topic knowledge it is unlikely that he or she will be able to try these various approaches and will not be able to trigger *understanding*. An engineering course consists of many concepts that have to be understood and although it may be difficult to assess whether a student has understood a concept well it is usually easy to determine that a student has *not* understood an engineering concept due to the settled, definite nature of engineering knowledge. That is, it is easy to fail a student in engineering but difficult to ensure that a student succeeds in *understanding* the material.

5.5.6 Final Thoughts and Suggestions for Further Research

An impression that I have been left with after writing this thesis is that little new has been developed in the field of education since the ancient Greeks. Most of the educational ideas that we regard as new were thought of many centuries ago; for example, the social construction of knowledge was discussed by St. Augustine. Modern educational research in many instances has merely re-invented the wheel or refined the wheel but has produced little that is fundamentally new. This may explain why mathematics and science education has had no or limited improvement during the 20th century. As mentioned above, Wittgenstein is one of the few thinkers that has produced fundamentally new thoughts about knowledge and *understanding* and, by implication, education.

As far as improving the pass rate in engineering is concerned, the following is a brief recapitulation of the points that need attention:

- The most important result of the above research is that the curriculum must be designed around what an average student can cope with in four years and not, as is done currently, around what is required in industry or what professional bodies believe engineers need to know. Industry and the professional bodies can make suggestions but the final deciding factor must be the average students' capabilities. The curriculum must be truly student centred.
- Due to the nature of engineering knowledge the current approach to teaching engineering using lectures, text books, laboratories, and tutorial sessions should be continued. However, more use should be made of modern technology particularly to reproduce still and moving images.
- Engineering educators must have a good engineering knowledge as well as a good pedagogical knowledge. In particular, they must be aware of the *event nature of understanding* discussed above. That is, they must appreciate the fact that in order to trigger *understanding* in their students they may have to approach a particular topic from a number of different perspectives and that *understanding* is a concept that is not well understood.
- Due to the mathematical/hard science nature of engineering it is easy to determine that an engineer has *not* understood a topic. Hence it is easier to fail a student engineer than a student undertaking studies in the humanities or social sciences in which there may be a number of acceptable alternate responses to assessments. In addition, it is difficult to determine how much an engineer has understood if his or her *understanding* is incomplete.
- Due to the large amount of knowledge involved in engineering the engineering curriculum must stick to only engineering topics. Other topics

such as finance, project planning, sustainable development, etc could be covered in a post-graduate diploma or master's degree. They should not be covered in an undergraduate degree for the reasons discussed above.

- All engineers should be made aware of much of the content and ideas in chapter two so that they do not become disillusioned and are fully cognisant of what an engineering education actually is and they should be encouraged to continue their education in the humanities, social sciences, etc once they have completed their engineering degree.

Areas of future research that have come out of the above thesis are the following:

- A set of diagnostic tools needs to be developed in order to determine *exactly* what engineering students know when they begin their tertiary studies: that is, their prior knowledge. As a practicing lecturer, with over 20 years' experience, I know that most engineering lecturers have a sketchy knowledge of exactly what any particular first year engineer knows. This is partly due to the wide range of standards produced by schools in the modern nationally controlled school system and to the general nature of school assessments. The development and verification of this set of diagnostic tools will be a large task and could easily form the content of a similar thesis to this one.
- Research needs to be undertaken into the phenomenon of *understanding* because there is little in the literature about this phenomenon and there is little understanding of *understanding*. This is strange because a key requirement of any education is that the students understand the material in the curriculum.
- Research needs to be undertaken into fundamentally different ways of presenting engineering, mathematics, and science knowledge so that if one method does not trigger *understanding* in the students the educators have an arsenal other approaches that they can try. Again this would be a large task and could form the basis of another thesis.

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APPENDICES

Appendix A.1 and appendix A.2 give the two quotes, referred to in the chapter three on teaching and learning, that summarise many of the topics that were discussed in that chapter.

Appendix A.1: A Quote from Poincaré

"How it is that there are so many minds that are incapable of understanding mathematics? Is there not something paradoxical in this? Here is a science which appeals only to the fundamental principles of logic, to the principle of contradiction, for instance, to what forms, so to speak, the skeleton of our understanding, to what we could not be deprived of without ceasing to think, and yet there are people who find it obscure, and actually they are the majority. That they should be incapable of discovery we can understand, but that they should fail to understand the demonstrations expounded to them, that they should remain blind when they are shown a light that seems to us to shine with a pure brilliance, it is this that is altogether miraculous.

And yet one need have no great experience of examinations to know that these blind people are by no means exceptional beings. We have here a problem that is not easy of solution, but yet must engage the attention of all who wish to devote themselves to education" (Poincaré, 1952).

Appendix A.2: A Quote from Montaigne

“[It is more important that a tutor has] character and understanding than learning; and that he should go about his job in a novel way.

[…] I should like the tutor to correct this practice [of learning by rote], and right from the start, according to the capacity of the mind he has in hand, to begin putting it through its paces, making it taste things, choose them, and discern them by itself; sometimes clearing the way for him, sometimes letting him clear his own way. I don’t want him to think and talk alone; I want him to listen to his pupil speaking in his turn. Socrates, and later Arcesilaus, first had their disciples speak, and then they spoke to them. *The authority of those who teach is often an obstacle to those who want to learn* [Cicero].

[…]

If, as is our custom, the educators undertake to regulate many minds of such different capacities and forms with the same lesson and a similar measure of guidance, it is no wonder if in a whole race of children they find barely two or three who reap any proper fruit from their teaching.

Let him [the student] be asked for an account not merely of the words of his lesson, but of its sense and substance, and let him judge the profit he has made by the testimony not of his memory, but of his life. Let him be made to show what he has just learned in a hundred aspects, and apply it to as many different subjects, to see if he has yet properly grasped it and made it his own, planning his progress according to the pedagogical method of Plato. It is a sign of rawness and indigestion to disgorge food just as we swallowed it. The stomach has not done its work if it has not changed the condition and form of what has been given it to cook.

Our mind moves only on faith, being bound and constrained to the whim of others’ fancies, a slave and a captive under the authority of their teaching. We have been so well accustomed to leading strings that we have no free motion left; our vigour and liberty are extinct. *They never became their own guardians* [Seneca]. […]

Let the tutor make his charge pass everything through a sieve and lodge nothing in his head on mere authority and trust; let not Aristotle's principles be principles to him any more than those of the Stoics or Epicureans. Let this variety of ideas be set before him; he will choose if he can; if not, he will remain in doubt. Only the fools are certain and assured. *For doubting pleases me no less than knowing. [Dante]*

For if he embraces Xenophon's and Plato's opinions by his own reasoning, they will no longer be theirs, they will be his. He who follows another follows nothing. He finds nothing; indeed he seeks nothing. *We are not under a king; let each one claim his own freedom* [Seneca]. Let him know that he knows, at least. He must imbibe their ways of thinking, not learn their precepts. And let him boldly forget, if he wants, where he got them, but let him know how to make them his own. Truth and reason are common to everyone, and no more belong to the man who first spoke them than to the man who says them later. It is no more according to Plato than according to me, since he and I understand and see it in the same way.
[…]

It is the understanding, Epicharmus used to say, that sees and hears; it is the understanding that makes profit of everything, that arranges everything, that acts, dominates, and reigns; all other things are blind, deaf, and soulless. [To learn one must] rub and polish our brains by contact with those of others" (Montaigne, 1943).

Appendix A.3: A Summary of 'The Process of Thought' by Dewey

This appendix is referred to in sections 3.2.3.3 and 3.3.2.5 and summarises Dewey's ideas on the process of thought (Dewey, 1963). For an alternative view on thinking from the perspective of a philosopher see Heidegger's 'What is called Thinking?' (Heidegger, 2004). The summary of Dewey's work is as follows and the bold emphases are mine:

A.3.1 What is Thinking?

There are many types of thinking such as an uncontrolled stream of consciousness which produces nothing worthwhile, imagination which is directed at something not present, etc. These types merge into one another and are not easy to distinguish.

The most productive thinking is reflective thinking. "Reflective thinking is active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends."

Reflection implies that something is believed based on evidence, that is, present facts suggest other facts making one consider how much the one may be regarded as a warrant for the belief in the other.

Reflective thought begins with some perplexity or doubt, that is, one cannot just 'sit and think'; something has to occasion thinking. It continues with an active attempt to remove the perplexity or doubt. A difficulty in the process of removing the perplexity or doubt prompts reflective thought. A solution is suggested by one's past experience and fund of relevant knowledge.

Reflective thought can be short circuited if one jumps to conclusions and does not undertake sustained thought and maintain a protracted state of doubt. ***Real*** justifications must be found for conclusions drawn.

A.3.2 Why Reflective Thinking must be an Educational Aim.

Reflective thought makes possible action with a conscious aim, that is, it reduces the tendency for one to act impulsively and moves one to intelligent considered action. It makes possible systematic preparations. It enriches things with meaning, connections, inferences, and symbolic significance. It gives one some control over the future.

Reflective thought develops well only with some educational input but wrong thinking can be harmful, therefore one must take care when one is training others to think. ***However, there are no set exercises that may be used to train one to think.***

Reflective thought often does not occur because wrong ideas have become socially accepted due to poor understanding, many believe superstitions, people follow passions, ignorance, wrong difficult to change ideas get planted in people's minds when they are young, and language can mislead. In addition, one believes what one wants to believe, one jumps to conclusions, one fails to test ideas, one generalises, and one takes too much cognisance of authority figures.

To think well there must be a union of the right attitudes with skilled methods (such as logical manipulations) and knowledge. That is, one must be open-minded (have an alert curiosity and a spontaneous outreaching for the new), one must direct one's attention wholeheartedly to a particular problem, one must think through the consequences of one's conclusion or solution, and one must have a general readiness to think on all matters.

A.3.3 Analysis of Reflective Thinking.

Reflective thought requires one to observe via the senses or memory to get the 'facts of the case'. Reflection then involves considering courses of action by using anticipation, supposition, conjecture, imagination, etc. The course of action is then tested to see if it fits the data and what its consequences will be. This process forms a continuous feedback loop:

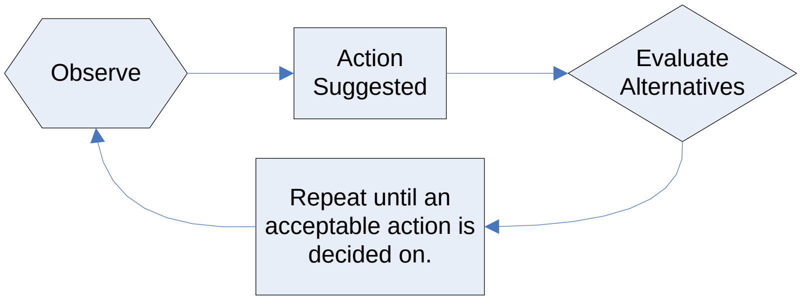

Figure A.1 The Thinking Feedback Loop

Reflective thought therefore has five phases: a) an initial suggested solution to a perplexity that does not work initiates reflective thought, b) the intellectualisation of the problem although often it is not certain what the real perplexity is but once the problem is defined it is ‘half solved’, c) the testing of various hypothesised solutions to see if they fit the facts and the gathering of more data from these tests if they do not (a good thinker makes use of errors and mistakes), d) reasoning based on experience and knowledge is used to develop ideas (mathematics is often used in the reasoning process to develop and test solutions), and e) the proposed solution must be experimentally verified.

The above phases do not follow a fixed order and may have many sub-phases and overlap with each other.

Past experience and knowledge are important for developing good theories and previous facts should be carefully reviewed, organised, and related to one another so that new productive theories may be developed.

A.3.4 The Place of Judgement in Reflective Activity

"Judging is the act of selecting and weighing the bearing of facts and suggestions as they present themselves, as well as of deciding whether the alleged facts are really facts and whether the idea used is a sound idea or merely a fancy."

Judgement is required when something is not immediately obvious, that is it arises from doubt and controversy. It defines the issue by selecting evidential facts and appropriate principles which then interact with each other.

Judgement of this type is partially inborn and partially due to past experience. Alertness, flexibility, and curiosity are essential. Dogmatism, rigidity, prejudice, caprice arising from routine, passion, and flippancy are fatal to good judgement.

Learning builds a stock of concepts but it is not wisdom; information (facts) does not guarantee good judgement; memory is merely a store of meanings for future use; it is judgement that selects in a time of 'emergency'. One should judge warily, subject to future confirmation.

Through judging confused data are cleared up and seemingly incoherent and disconnected facts are brought together. The clearing up is analysis and the bringing together is synthesis. The method used to make a discovery and the method used after a discovery to get the same results are different. The second method shows how thought may be organised. Synthesis takes place whenever we grasp the bearing of facts on a conclusion or of a principle on facts. Analysis takes place when judgement involves discernment and discrimination; synthesis takes place when the mind forms an inclusive situation within which selected facts are placed.

When solving a problem or resolving a situation a largely unconscious development of logical attitudes and habit comes first. A conscious method develops only after the problem has been resolved, therefore educators must be wary of forcing logical methods on students. A conscious step-by-step method is only useful if it is used to throw light on a new similar situation. Repeated use is what gives a method its definiteness not imposition by an educator; in fact, forcing definite methods on students can hinder their ‘natural’ approach to problem solving. Education is neither totally analytic nor totally synthetic and each process feeds on the other.

A.3.5 Understanding: Ideas and Meaning

Ideas (suggestions, conjectures, guesses, hypotheses, and theories) are elements used to form judgements, they help to organise data, are tools of interpretation, and they direct enquiry and examination. Ideas are tools used to search for material to solve a problem. Action directed by ideas is the only alternative to stupidity and learning by chance experience.

To understand is to grasp meaning, that is to see an event, thing, or situation in its relation to other things; to note how it operates; to know what consequences follow from it; to know what causes it; to what use it can be put; and to take it out of its isolation and comprehend how it relates to the universe. There are to modes of understanding, that is, connaitre and savoir.

An increase in one’s store of meanings makes one conscious of new problems, while only through translation of the new perplexities into what is already familiar and plain do we understand or solve these problems.

Things initially gain meaning by entering into a ‘context of use’. The ability to understand is eminently furthered by language, by elaboration of a series of meanings, and by reasoning.

Things gain meaning when they are used as a means to bring about consequences, or as standing for consequences for which one has to discover means. The relation of means-consequences is the heart of all understanding. Teaching with understanding involves setting up the conditions for active use as a means of bringing consequences to pass or finding means to realise consequences already thought of.

A.3.6 Understanding: Conception and Definition

Concepts are stable standardised meanings which enable one to generalise, to extend, and carry over one's understanding from one thing to another. They economise one's intellectual efforts and give one a wider perspective on specific things. Concepts are therefore crucial to education. "Science consists in grouping facts so that general laws or conclusions may be drawn from them" (Dewey quoting Darwin).

Lessons should leave ideas which are definite and general, that is, leave concepts. Lessons must not be remote from a student's prior experience and understanding.

Conceptions are ***not*** formed by extracting common traits from ready-made objects; they begin with experiences and become definite with use and application. They also become more general with use and a synthesis of ideas takes place between previously unrelated ideas.

Vague concepts can be a major source of misunderstanding and mistakes.

Definition and classification are the concepts that are the marks of a science. Concepts are organised as follows. Intension: a meaning which is detached, single, self-contained, and homogeneous throughout; that is, the definition of something. Extension: the use of a meaning to mark off and group together a variety of distinct existences; that is, the classification of something. Definitions may be denotative (direct experience of an objects properties, such as colour, is required), expository (a dictionary definition or description), or scientific (causation, production, or generation are the defining factors).

A.3.7 Systematic Method: Control of Data and Evidence

Judgement, understanding, and conception are all constituents of the reflective process in which a perplexing, confused, and unsettled situation is transformed into one that is coherent, clear, and decided or settled. The reflective thinking process is a closed loop as follows:

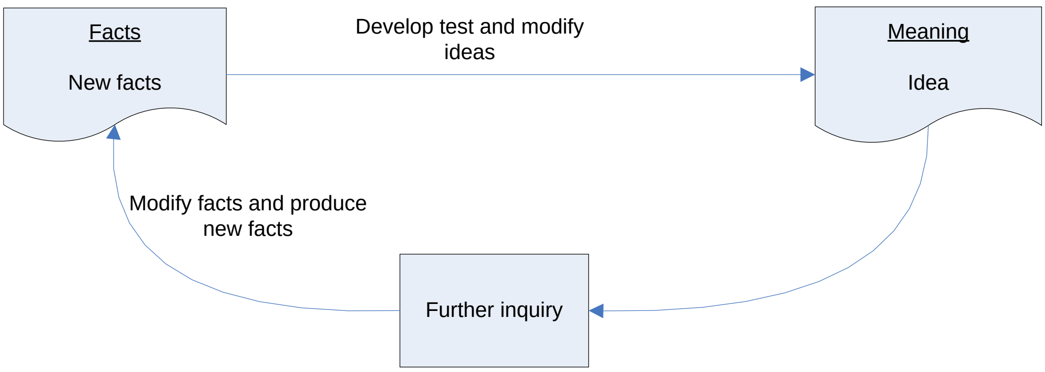

Figure A.2 The Reflective Thinking Process

Only facts relevant to a perplexity must be used, however hypotheses (initially multiple) and ideas can be used to search for further relevant facts; often via thoughtful observing, collection, contrasting, and comparison. Deliberate experiments may also be constructed. "The object of experimentation is the construction, by regular steps taken on the basis of a plan thought out in advance of a typical crucial case, a case formed with the express reference to throwing light on the difficulty in question."

One must take care to avoid bias due to interest, habits, preconceptions, small sample size, extrinsic influences, etc.

Ideas for testing hypotheses ***"just come"*** but usually to people prepared by interest and prior thought.

A.3.8 Systematic Method: Control of Reasoning and Concepts

A system is a set of relations between concepts. Well delineated basic concepts (including mathematical concepts) promote further discoveries, inventions, and allow the forces of nature to be controlled. Definition, general formulas, and classification are the devices by which the fixation of meaning and its elaboration into its ramifications are carried on. These items are not ends in themselves but are instrumentalities for facilitating understanding, aids to interpretation of the obscure, and explanations of the puzzling. In addition, one must regularly summarise and review one's work to get rid of debris and irrelevant information.

A theory must be experimentally verified, that is, thinking must begin and end in the domain of concrete physical observations; this does not mean random physical fiddling. It should be noted that simulations are not sufficient.

The ultimate educative value of all deductive processes is measured by the degree to which they become working tools in the creation and development of new experiences.

Much education is ineffective because of the isolation of meanings from facts, that is, learning becomes effective when relationships are understood rather than the students merely learning isolated facts. Further, students must learn to justify their view with reasoning and facts, and if they have understood they must be able to apply general principles to new concrete individual cases. Finally, teaching should not start with definitions, rules, general principles, and classifications. It should rather show why these are necessary and how they arose.

A.3.9 Activity and the Training of Thought

Practical exercises in schools should be used for presenting typical problems to be solved by personal reflection and experimentation and by organising definite bodies of knowledge leading later to more specialised scientific knowledge. Ultimately students must become versed in the methods of experimental inquiry and proof.

For projects to be educative they must meet the following criteria:

- They must be of interest to the students but of a thought provoking type of interest.
- The activity must be worthwhile intrinsically to the student (not the educator) and not be just fun.
- They must awaken new curiosity and create a demand for information.
- The must involve a considerable time span for execution, that is, the aim of the project must be capable of development. The educator's role is to ensure this.

A.3.10 From the Concrete to the Abstract

Just because a student is manipulating physical objects it does not mean he or she is learning. The student must manipulate in such a way that he or she is compelled to think how things are related to each other and how the required ends are to be obtained. That is, physical objects should inspire abstract thought, about objects' properties, consequences, structures, cause and effect, etc., so that the student moves from the concrete thought to the abstract thought.

Students must, over time, develop an interest in intellectual matters for their own sake and a delight in thinking for the sake of thinking. This process of learning abstract thought must be lead by educators.

Education should promote both abstract thought and concrete thought bearing in mind that most people are biased towards practical thinking.

A.3.11 Language and the Training of Thought

Language or, in general, signs are necessary for thought and communication but the ‘signs’ should be compact, portable and delicate so that they do not distract one’s attention. Language selects, preserves, and applies specific meanings. In addition, signs make it possible to use meanings in new contexts and situations which is the key to judgement and inference.

Language and signs (symbols) are instruments for organising meaning and therefore languages and signs are important to learning the meaning of things. Symbols get meaning when one has had experience of what the symbols represent.

Therefore, because symbols are important, educators must make sure that students do not develop vague or confused uses of symbols or learn to recite recipes without understanding what the underlying symbols mean. In order to do this, educators must enlarge the student’s vocabulary, render their vocabulary more precise, and form habits of consecutive discourse (that is, students must learn to connect and organise meaning). In particular technical terms should be introduced slowly and in the correct situation and the educator should ensure that the students use the terms with understanding and do not produce hollow cant. Note that if a concept is not understood there is nothing to be gained by using familiar terms in place of technical ones.

A.3.12 Observation and Information in the Training of the Mind

Thinking is organising subject matter with reference to discovering what it signifies or indicates. If personal observation and the communication of information by others (via books, speeches, etc.) are rightly conducted half the logical battle to understand something is won. Therefore making observations is an important part of training the mind.

Observation is not an end in itself and an educator must bring out the importance of particular observations. Generally people are impelled to observe because they have a sympathetic interest in extending their acquaintance with something; that is they are curious. In addition, one makes analytic observations because one wants to undertake some activity. Observations are often used to test an idea or plan so that a felt difficulty can be turned into a question that guides subsequent thinking. Observations without a 'problem' to be dealt with are pointless and similarly observations in education must have an aim and subsequent observations should form an intellectual progression. In particular educational observation should be exploration and inquiry for the sake of discovering something previously hidden and unknown; this something being needed to reach some end. These educational observations should take note of the structure and function of the thing being observed. Ultimately students should be trained in the formal scientific method.

For problems to become definite and suggested explanations significant one should alternate one's observations between a wide soaking in of relevant facts and a minutely accurate study of a few selected facts, that is, to give an observer and overall but vague picture and a precise view of parts of the overall. However, one should note that training the senses by means of isolated exercises does not have any transfer value and is therefore of little use in education.

Information that is communicated directly to a student (from the educator or from books) without concrete observations should be relevant to a question that is vital to the students own experience and should not be communicated in such a way that it is a barrier to effective thinking, to initiative, or to curiosity.

A.3.13 Some General Conclusions

To oversimplify, to exclude the novel for the sake of prompt skill, to avoid obstacles for the sake of averting errors is as detrimental to learning as to try to get students to formulate everything they need, to state every step of the procedure by which a result is obtained. Only once a subject has become familiar do summarising and organisation become important. Students should, in general, not be made aware of the thinking process they are going through; rather control should be exercised by the setup of the situation itself. The educator however must guide the student through areas of particular perplexity or of repeated errors. To solve a problem one must initially become totally absorbed in it and examine it in detail and from as many angles as possible. It is then a good idea to totally put the problem aside for a while and often it will solve itself.

Students should be allowed ‘play’ but just ‘fooling around’ should be limited. To prevent fooling the students should have to forecast the outcomes of their activities. Serious mental play is largely keeping an open mind and having an interest in the ‘truth for truths’ sake; that is, avoid dogmatism and prejudice, and maintain intellectual curiosity and flexibility.

Educators should be aware that purely concentrating on outcomes makes work drudgery so to prevent drudgery an educator should make the process of learning interesting or, alternatively, make the outcome so attractive that some drudgery will be tolerated by the students. This is necessary because students need to learn to balance the outcome of an activity with the means to achieve it; for example, a good artist knows his or her materials and methods well but can also conceive of worthwhile creations to use the means and materials on. An educator must arouse enthusiasm, communicate large ideas, and evoke energy, but must at the same time be empowering. That is, an educator must ensure that the attention to detail and the techniques that ensure mastery over execution are developed.

Psychologically people are interested in the new, the precarious, and the problematic rather than what is ‘old-hat’. Therefore educators should use the familiar and ‘near’ to analyse the sensational, extraordinary, and incomprehensible because even these interesting aspects must be grounded in a student’s prior experience. Educators must not only teach what is familiar and ‘near’. The best thinking occurs when the easy and the difficult are duly proportioned. The ‘remote’ ideas provide the stimulus and motive, and the ‘near-at-hand’ provides the point of approach and the resources. A spiral process is set up: foreign subject matter is transformed through thinking into a familiar possession which becomes a resource for judging and assimilating additional foreign subject matter. Observation supplies the ‘near’ and imagination supplies the remote; that is, most topics studied need concepts to be imaginatively realized because imagination supplements and deepens observation. A good educator is able to communicate the experience of the human race in such a way that it uses, develops, and extends the students narrow personal experience but does not swamp it, that is, the student is stimulated to think.